SC-21/ONR Science and Technology Manning Affordability Initiative
Thrust 3 - Human Centered Design Environment

Human Engineering Task Analysis Operational Sequence Diagrams (OSDs)

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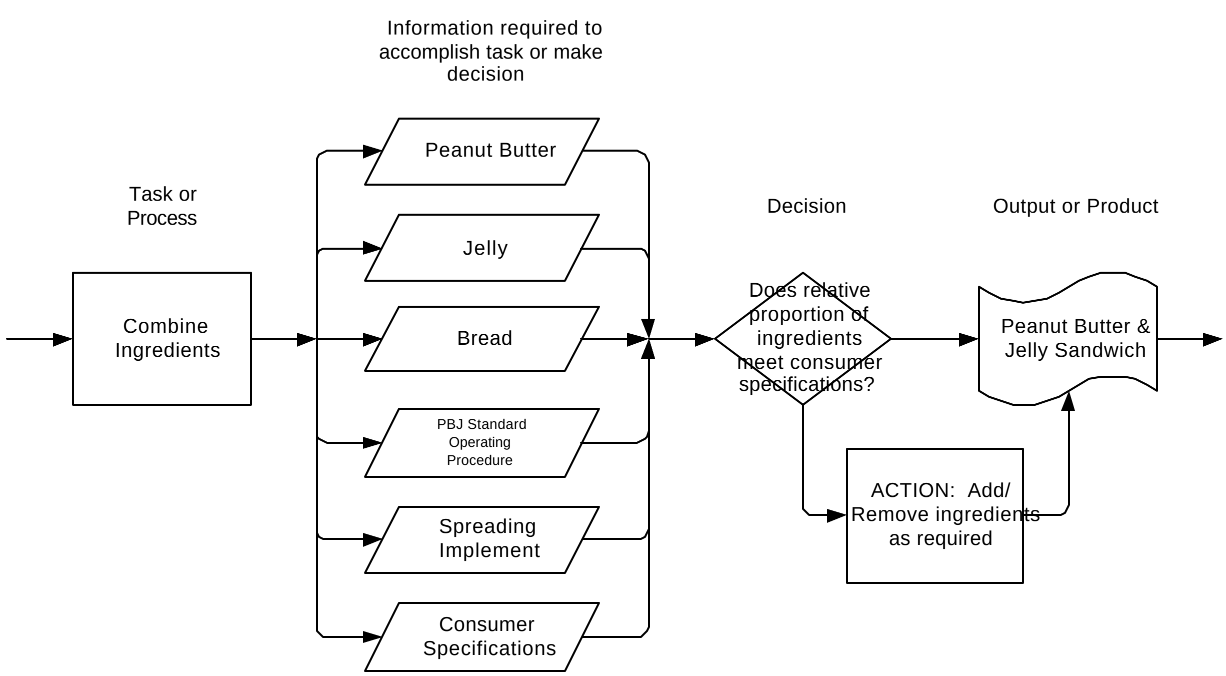
Introduction

This task analysis of human engineering is being produced as an intermediate product within the SC-21 Science and Technology Manning Affordability Initiative. The method that has been selected to represent the results is the operational sequence diagram (OSD). The accompanying data sheets, along with the attached OSDs, are intended to serve two purposes. First, as a general task analysis of human engineering, it is intended to form a basis for a detailed cognitive task analysis that will examine critical steps within the human engineering process and the interaction between human factors practitioners or human engineers and systems engineers. This cognitive task analysis will provide design guidance for the development of a Human-Centered Design Advisor (HCDA), which is intended to be a decision support tool to assist systems engineers in identifying and addressing human factors issues. Coupled with a similar set of OSDs that were produced for systems engineering, the human engineering OSDs have enabled the identification of significant human engineering inputs to the systems engineering process and vice versa. Second, it is intended to serve as an inventory of tasks, decisions, and information requirements to aid in the development of the Human-Centered Design Environment (HCDE). The prototype HCDE being developed in this project includes a set of integrated engineering tools, selected to enable a design or development team to include humans within system designs earlier and more accurately. These OSDs will serve as a baseline to evaluate the functionality of the prototype HCDE and its integrated tools and will also provide guidance for the definition of test scenarios to evaluate the usability of the HCDE.

Task Unit



Introduction to Use of OSDs for Task Analysis

Different symbols are used in OSDs to represent different elements of the human engineering process. These symbols are frequently used in the recurring pattern of a **task unit**. (See figure above for an example of a task unit from the creation of a peanut butter & jelly sandwich.) Within a task unit, the order of the symbols is not intended to represent any temporal flow or order.

The first symbol within a task unit is a rectangle that represents the title or description of the task. The second element is one or more parallelograms, each of which represents a separate piece of information or an item required to accomplish the task or make a decision. A diamond, representing a decision to be made, follows the information requirements. The final piece of the typical task unit is a wavy rectangle, which signifies a defined output or product of the task or decision. Although not part of the typical task unit, “action” boxes are used to represent an implicitly defined discrete process that may be taken as an independent action. This notionally could be decomposed further, but there is nothing to be gained by the exercise. For example, in the case of the peanut butter and jelly sandwich, given that it is already known how to spread the ingredients and have the tools to do so, it is implicit that the action "Add/Remove ingredients as required" can be performed to meet the consumer specifications. This is done to simplify the appearance of the OSDs.

Operational Sequence Diagrams were chosen as the method to represent the results of this task analysis since they allow the depiction of the most critical components of the process – the **tasks** themselves, their accompanying **decisions**, **information** required to complete tasks or make decisions, and **products** or other outputs. Like all forms of task analysis, OSDs have their limitations. One of their deficiencies is that when applied to a process such as human engineering, they imply a greater degree of sequence, order, and timing than is intended to be captured. Since the exact sequence of many tasks may vary greatly or even overlap, the representation of the most important tasks and decisions is of greater importance than their order. Additionally, the tasks and decisions that make up the human engineering process may not be all represented at an even level of detail, concreteness, or repeatability. For example, a task analysis of the process by which an artist creates a painting may consist of the following tasks:

1. Obtain paint
2. Obtain canvas and brushes
3. Paint picture

Given this representation of the tasks involved in artistic painting, it is doubtful that anyone could fully understand the creative and abstract nature of the painting process or that by following it, an amateur could create an accurate reproduction of a famous work of art. The goal, however, of these diagrams is to support the design of tools that support the human engineering process and to provide a framework for further examination of difficult or critical tasks and decisions through further analysis. Returning to the painting example, tools to aid and speed the completion of steps 1 and 2 would free up more time for the painter to concentrate on the most crucial step, painting the picture itself. Similarly, step 3 would be identified as a task in need of further exploration and definition, as could be accomplished through a subsequent cognitive task analysis.

Within this set of OSDs, many of the tasks, decisions, products, and information requirements exhibit a distinct military or Department of Defense flavor or quality. This trend holds particularly true for information requirements and for the OSDs dealing with the generation of requirements. The overall flow of the process as captured in the OSDs, however, is intended to be applicable to the development of non-military systems. For example, the first task unit in OSD HE110 deals with the review of mission needs, existing scenarios, and threats, and includes information requirements of the Mission Profile, Comparison Systems, Concept of Operations and Threat. For an automobile manufacturer, these information requirements would not exist as precisely defined as here, but parallel information requirements such as Market Trends, Customer Surveys, Current Product Line, and Current & Predicted Competitor Vehicles would be relevant.

Scope of Human Engineering OSDs

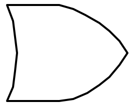
The first page of the OSDs shows a high-level flow diagram of the process described by the set of OSDs. Each small box within this diagram represents a separate OSD, each of which is made up of several task units and other elements and may cover two to seven pages. Only the most general flow has been shown in this diagram. Multiple cycles of iteration and interconnection are assumed but not explicitly depicted.

The flow of tasks in the process follows that of the systems engineering process described by accompanying systems engineering OSDs. The high-level breakdown includes requirements analysis, function analysis, design synthesis, and systems analysis (testing and evaluation). The first step describes the initial review of the mission while considering the inclusion of humans in the system. This involves first defining the projected user, followed by the creation of requirements based on what the user must perform, combined with human physical and performance capabilities and limitations. The function analysis step ensures that when the functions are broken down, the level of detail and flow are adequate for those functions that are to be performed by humans. The functional architecture developed by the systems engineers is also assessed for adequate coverage of the human-related requirements defined earlier. The most extensive tasks in synthesis, begin with the assignment of the functions to resources (hardware, software, human or a combination). The functions to be performed by humans can then be decomposed into subsequent tasks, including the characteristics of and interactions between them. Using the list of human tasks, interfaces are then defined between humans and other humans or with other systems (internal and external). Interfaces are described at three levels, including the individual interface level, combinations of interfaces that one human will interact with, all the way up to the level of combinations of humans, which entails describing crew or team interactions by noting the added effects of multiple users. Throughout the interface definition process, additional tasks that are created by the addition of the interfaces, or combinations must be added to the previous task list and re-circulated through the process. The last step of the synthesis phase is the estimation of performance, workload and training levels, which are derived from the concepts and designs at this point. Models are used to identify inappropriate and unsafe levels. From this, tasks may be modified to arrive at an optimal design. A sensitivity analysis and trade-offs are performed to assist in the selection of candidate designs by tweaking and weighing alternatives. The last phase of the human engineering process is the test and evaluation phase, which is actually ongoing throughout. This is merely a constant check of the designs and concepts with the end-users (or SMEs) and requirements. This phase promotes verification through the systems engineering process as well as synergy with the needs of the user population.

The start of the process assumes the external creation of a Mission Need Statement (MNS), Concept of Operations (CONOPs), and Operational Requirements Document (ORD). Additionally, it is assumed that an Analysis of Alternatives has been performed. The results of all of these analyses, or at least their most current iterations, are assumed to be available to those working within the human engineering process.

The focus of the OSDs is on human engineering aspects of system development up until Preliminary Design Review, and phases such as production and deployment are not covered. A single individual does not necessarily carry out the tasks and actions within this human engineering process. Instead, any number of individuals may accomplish these tasks serially or in parallel. The flow of work through the tasks should be assumed to follow a “bus stop” metaphor – if there are no passengers to be picked up or dropped off at a particular stop then there is no need for the bus to stop. In the same way, if a task or decision is not applicable to the system under design or if the action has already been satisfactorily completed, then there is no need to perform the action in question. As mentioned earlier, the process as represented contains a variety of references to the development of military systems. This is due in part to the fact that many of the sources used to develop these OSDs were of military origin. A list of the sources cited is located at the end of the document.

OSD Symbology Key

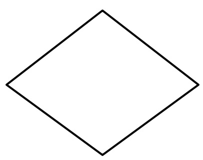


Action Cue / Trigger

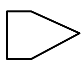
Task/Process

Information Requirement
(produced internal to the process)
(*Number represents OSD in which information requirement was produced*)

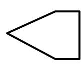
Information Requirement
(produced external to the process)



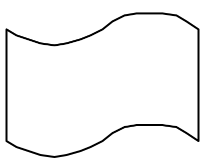
Decision



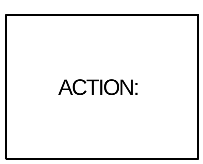
Task Feed ("Goes to")



Task Feed ("Comes from")



Output or Product



Action

Definitions

Cognitive Task Analysis [HE320] – A subset of the task analysis process that focuses on the identification of human mental processes and knowledge needed to perform certain tasks.

Comparison Systems [HE110, HE210, HE310] – Comparison systems are pre-existing systems that have been determined to be similar to the system under design in mission, purpose, function, or other relevant characteristics. The data that might be useful from such comparisons includes “Lessons Learned” from successes or failures of previous systems or other critical events. The comparison systems may be officially selected or agreed to by those working on the current system or they may be identified in a more informal manner.

Concept of Operations (CONOPS) [HE110, HE120, HE310] – A document that identifies the relationship, dependencies, and desired interfaces envisioned between the new or upgraded system and other existing or planned systems. It describes the operational structure, capabilities, integration, and the interoperability of all the operational and supporting systems.

Constraint [HE120, HE310] – A limitation or implied requirement that limits the design solution or implementation of the systems engineering process, which is not changeable by the enterprise, and is generally non-allocable.

Design Reference Mission (DRM) [HE110, HE310] – A mission or missions that the system under design will be required to perform.

Functional Architecture [HE110, HE210, HE310] – A hierarchical arrangement of functions and sub-functions, includes internal and external interfaces, that defines the system’s sequences, data flow and performance requirements.

Functional Element Allocation Options [HE120, HE320] – Potential alternatives for the allocation of a function or sub-function to an element of the system being designed. Allocation can be made to any combination of hardware, software, or humans. The system can also be designed such that the allocation is dynamic, and varies as a function of time or system state.

Functional Element List [HE310] – An inventory of the functions and sub-functions that are to be allocated to different portions of the system being designed.

Functional Flow [HE210] – The sequential relationship between functions.

Functional Requirement [HE120] – A description of what a system, sub-system or product must accomplish in order to produce the desired behavior and/or results.

Guidance [HE110, HE120, HE310, HE330, HE350, HE360, HE410] – Instruction or direction (e.g., political influence) provided in the determination of certain decisions and constraints. This input may be informal in nature.

Human Performance Requirements [HE310, HE330, HE340, HE350, HE360, HE410] – Criteria established which the human-allocated functions must meet.

Knowledge, Skills and Abilities (KSAs) [HE110, HE120, HE310] – A set of qualities that describe an operator/maintainer's area of expertise and background.

Lessons Learned [HE110] – Information that describes previous systems with similar missions (extracted through interviews, briefs, etc.) that may be compiled and applied to the design of present systems. This does not focus solely on the problems and errors, but also positive aspects that may or may not have been intentional (adaptations, preferences, etc.) but were found to be beneficial to the users.

Mandatory Function Allocation [HE310] – The assignment of a function to a particular resource (hardware, software or humans), which is required to perform the particular function.

Measures of Effectiveness (MOEs) [HE410] – Pre-determined variables that will be used to determine the impact of the implementation of a system.

Mission Needs Statement (MNS) [HE110, HE410] – A formal document, expressed in broad operational terms that documents deficiencies in current capabilities and opportunities to provide new capabilities.

Mission Profile [HE110] – A sequential description of the events of an entire mission.

Operational Environment [HE110] – The natural and induced environmental conditions or stimuli with which a system is expected to interface.

Operational Requirements Document (ORD) [HE110, HE120, HE320] – The definition of a specific concept in a system that is intended to establish measurable objectives for that system. The Operational Requirements Document follows the Mission Needs Statement, and includes minimum acceptable requirements for the system, critical system characteristics, and describes pertinent quantitative and qualitative performance, operation, and support parameters, characteristics, and requirements.

Performance Requirements [HE120, HE310, HE410] – The extent to which a mission or function must be executed, generally measured in terms of quantity, quality, coverage, timeliness or readiness that becomes measurable criteria for verification.

Physical Architecture [HE110, HE120, HE310, HE320, HE410] – A hierarchical arrangement of physical elements, components and sub-components, including internal and external interfaces, that satisfies the baseline requirements and will become a basis for a system design.

Points of Human Interface [HE330, HE350] – Places in the functional architecture where data, information, objects, etc. are transitioned between humans or humans and equipment. Information of interest includes the data that is to be transmitted, the nodes or elements between which data is transmitted, when the data is transmitted, and other interface-specific constraints, such as special conditions based on times and events.

Requirement – A statement that identifies a product or process limitation, capability, or physical characteristic. The different categories of requirements used within this document are Source Requirements, Derived Requirements, Operational Requirements, Functional Requirements, and Performance Requirements.

Scenarios [HE110] – A description of a sequence of events or activities that are representative of the intended use of a system or components of a system.

Subject Matter Expert (SME) [HE110, HE120, HE210, HE320] – An individual who possesses experience in a particular field that may be used for input of field-specific information and who may evaluate designs throughout the life-cycle process.

System Boundaries [HE120] – The boundaries of the system under design including all portions of the product to be produced by the project.

System Specification [HE310] – A document which states the technical and mission requirements for a system as an entity, allocates requirements to functional areas (or configuration items), and defines the interfaces between or among the functional areas.

System Use Scenarios [HE110, HE210, HE310, HE330, HE340, HE350, HE360, HE410] - Based on the system-level scenarios, the events or activities that are specific to the humans.

Threat [HE110] – Any means that an adversary, current or potential, can inflict damage to, or disrupt the efficient operations of, a system

Trade Study [HE120] – An objective evaluation of alternatives using the same criteria for each.

Acronym List

HE	Human Engineering
HCI	Human-Computer Interaction
HMI	Human-Machine Interface
KSAs	Knowledge, Skills and Abilities
MOEs	Measures of Effectiveness
OSD	Operational Sequence Diagram
SE	Systems Engineering
SME	Subject Matter Expert

HE High-Level Diagram

HE High-Level Diagram

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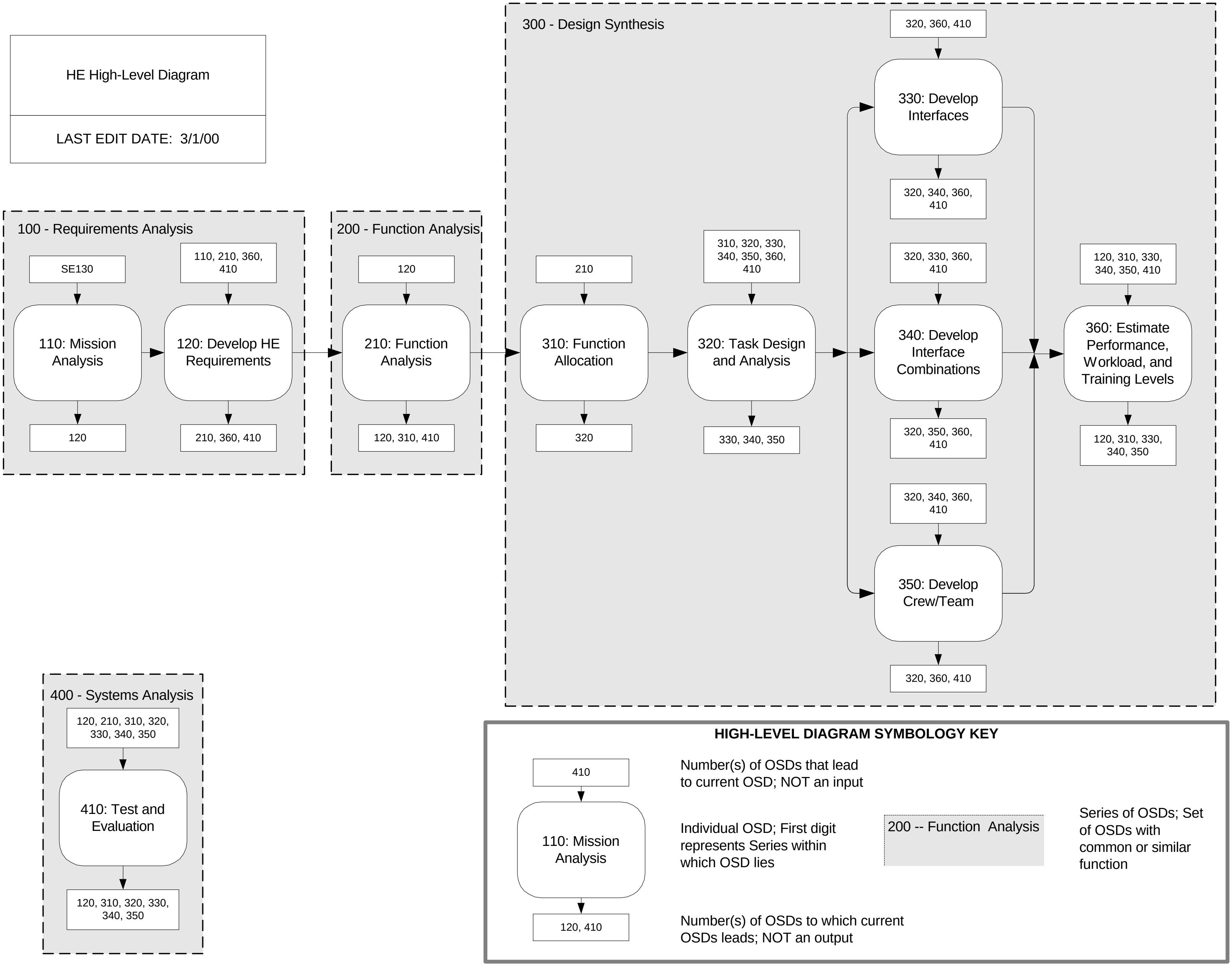

HE 110 – Mission Analysis

HE110 - Mission Analysis

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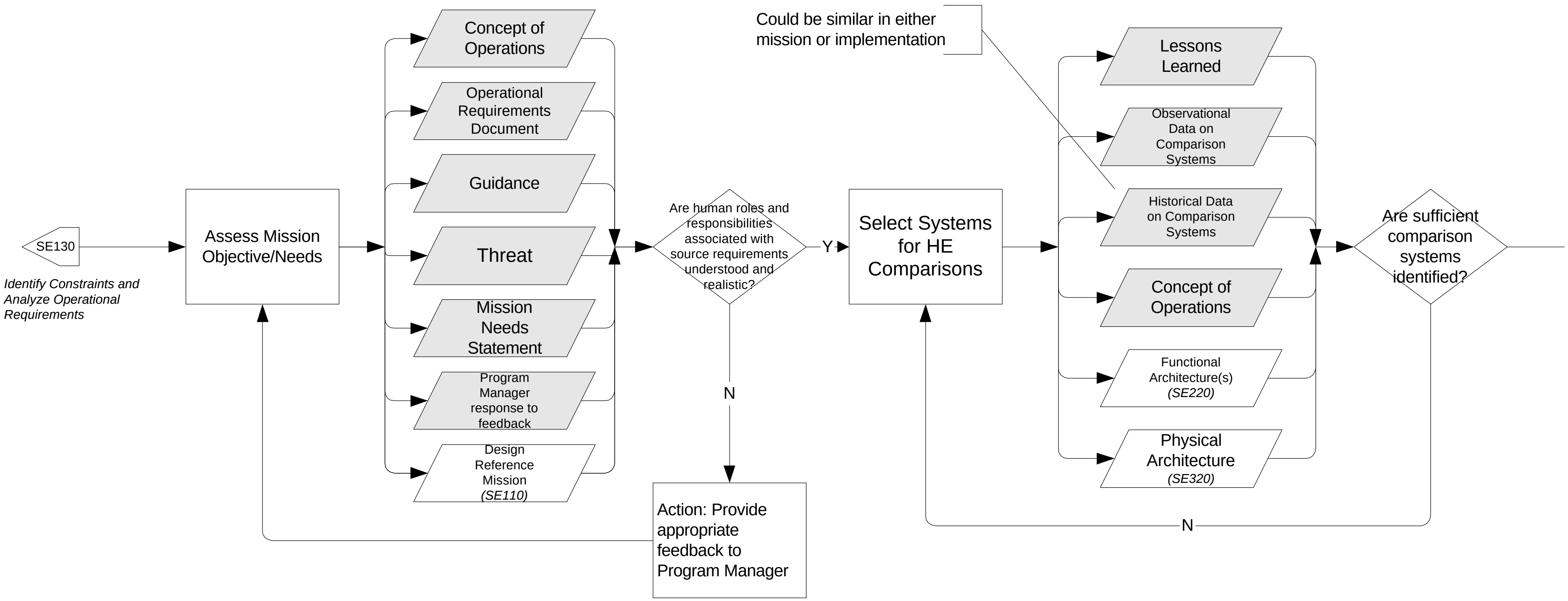
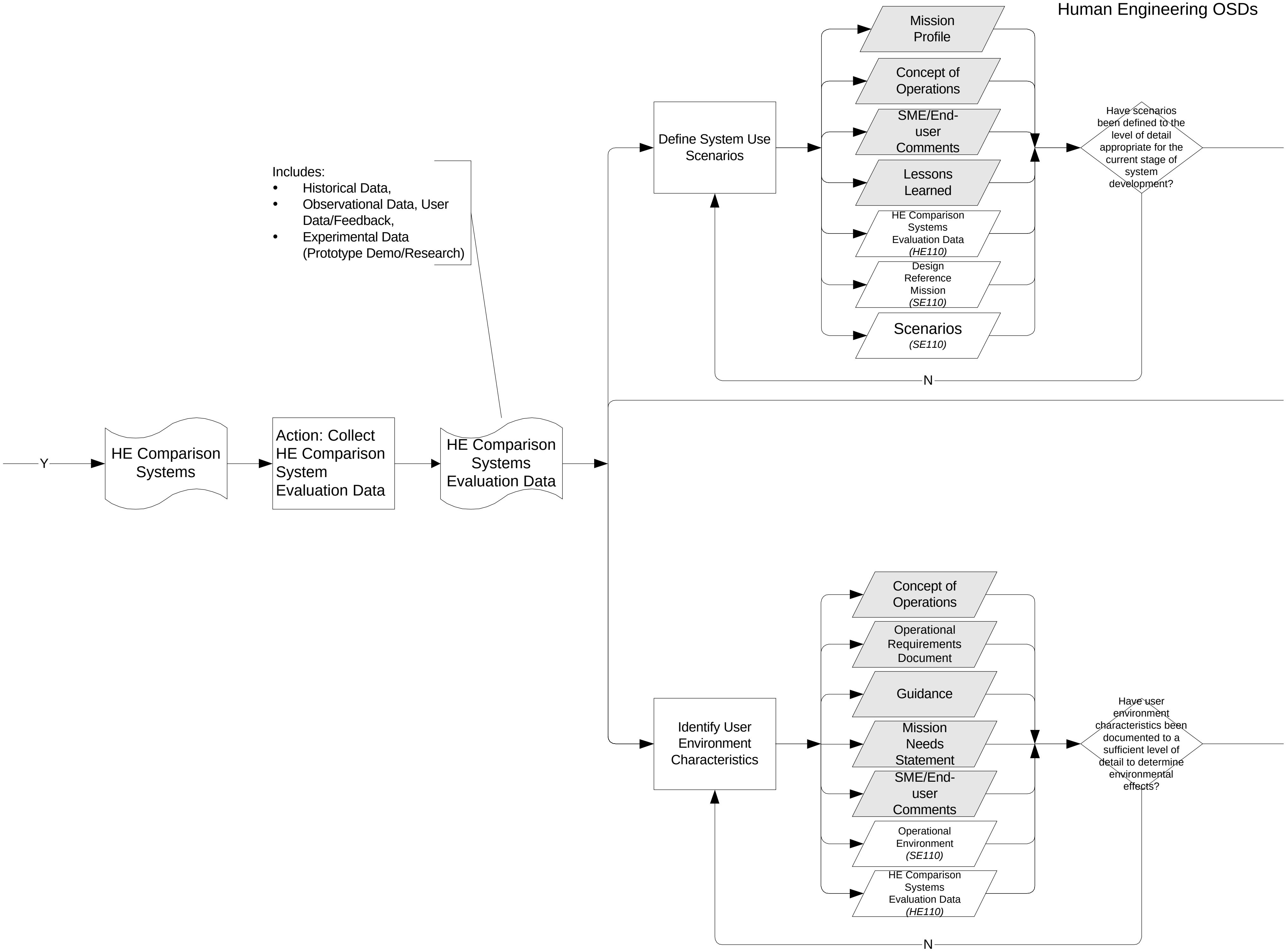
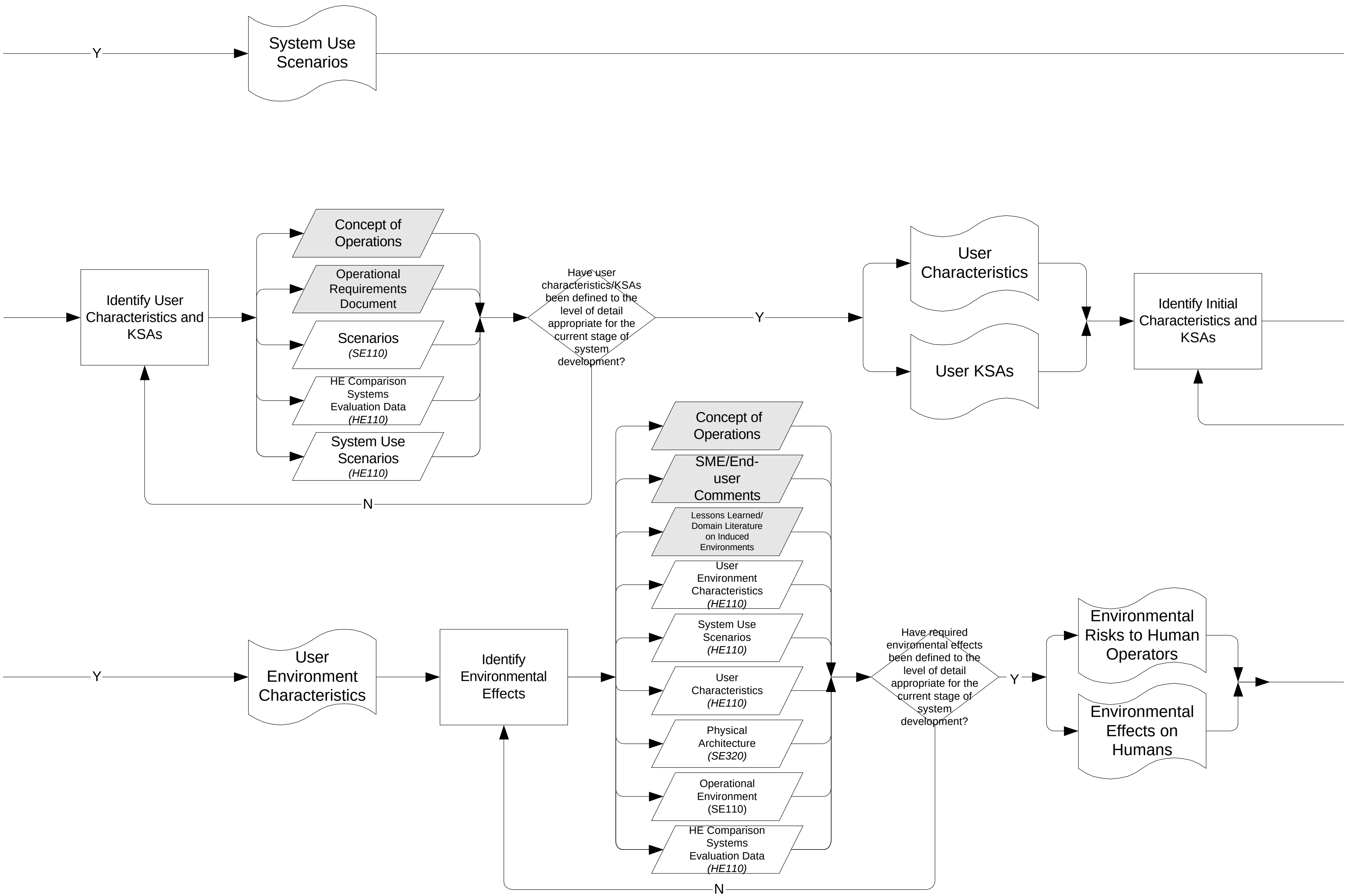
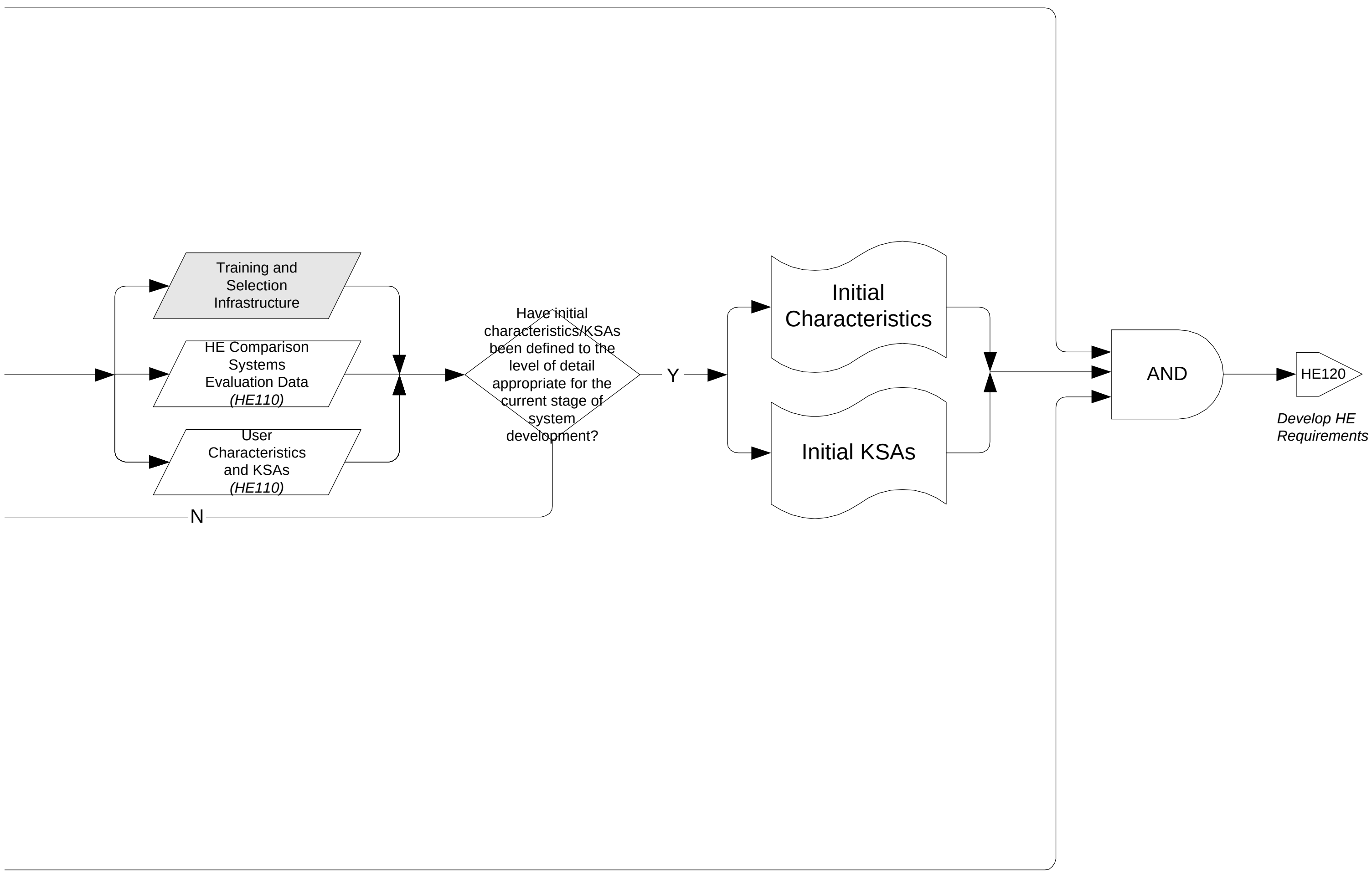



Y
HE Comparison Systems
Action: Collect HE Comparison System Evaluation Data
HE Comparison Systems Evaluation Data
Includes:
• Historical Data,
• Observational Data, User Data/Feedback,
• Experimental Data (Prototype Demo/Research)
Define System Use Scenarios
Mission Profile
Concept of Operations
SME/End-user Comments
Lessons Learned
HE Comparison Systems Evaluation Data (HE110)
Design Reference Mission (SE110)
Scenarios (SE110)
Have scenarios been defined to the level of detail appropriate for the current stage of system development?
N
Identify User Environment Characteristics
Concept of Operations
Operational Requirements Document
Guidance
Mission Needs Statement
SME/End-user Comments
Operational Environment (SE110)
HE Comparison Systems Evaluation Data (HE110)
Have user environment characteristics been documented to a sufficient level of detail to determine environmental effects?
N


Y
System Use Scenarios
Identify User Characteristics and KSAs
Concept of Operations
Operational Requirements Document
Scenarios (SE110)
HE Comparison Systems Evaluation Data (HE110)
System Use Scenarios (HE110)
Have user characteristics/KSAs been defined to the level of detail appropriate for the current stage of system development?
Y
N
User Characteristics
User KSAs
Identify Initial Characteristics and KSAs
Y
User Environment Characteristics
Identify Environmental Effects
Concept of Operations
SME/End-user Comments
Lessons Learned/ Domain Literature on Induced Environments
User Environment Characteristics (HE110)
System Use Scenarios (HE110)
User Characteristics (HE110)
Physical Architecture (SE320)
Operational Environment (SE110)
HE Comparison Systems Evaluation Data (HE110)
Have required enviromental effects been defined to the level of detail appropriate for the current stage of system development?
Y
N
Environmental Risks to Human Operators
Environmental Effects on Humans


Training and Selection Infrastructure
HE Comparison Systems Evaluation Data (HE110)
User Characteristics and KSAs (HE110)
Have initial characteristics/KSAs been defined to the level of detail appropriate for the current stage of system development?
Y
N
Initial Characteristics
Initial KSAs
AND
HE120
Develop HE Requirements

HE 110 – Mission Analysis

Narrative:

The first phase of the human engineering process is the determination of the overall purposes or objectives and capabilities of the system as well as the environment in which the system must operate based on source requirements. This will entail the definition of the basic functions that the system is intended to perform and the identification or creation of mission scenarios at the human level.

The feasibility of adding humans to the system is assessed first, then comparison systems are selected from previously defined systems that had similar missions or purposes and lessons learned that are used to define the scenarios and users. The focus in this stage is on the definition of the system boundaries, treating the system as a "black box", by defining inputs and outputs (e.g., characteristics of the users before and after training), the environment (including risks associated), and other constraints.

<u>Assess Mission Objective/ Needs</u>

Determine why the system is needed and assess the feasibility of including humans as part of the system based on mission and operational documents developed at this point as well as programmatic guidance. Given what the proposed system is expected to accomplish and its operational concept, determine the threat that must be addressed. This may be in the form of a description of the existing gaps in current capabilities that must be filled or a current system that needs to be replaced or upgraded. This is the first review of the system concept, developed by systems engineers, from a human engineering (HE) perspective. Therefore, before proceeding, feedback may need to be presented to the program manager regarding the human roles and responsibilities associated with the source requirements to ensure clarity and lack of ambiguity of the human roles.

Sources:

4. V2I2 section 1
5. section 6.1.1
7. sections 1.1.1, 1.1.2.2, 1.1.2.3
9. pages 84-85
10. section 6.1.2

<u>Select Systems for HE Comparison</u>

Previously designed or built systems (or subsystems) are essential for lessons learned and design guidance and must be selected for human engineering comparisons with the system under design. Comparison systems selected should have objectives or missions, requirements or implementation similar to that of the system being designed. Therefore, it may be easier to select HE comparison systems for evolutionary systems where the previous iteration of a design will be used for comparison. For new systems, it is useful to identify similar systems or subsystems that perform the required functions within the given constraints. A variety of comparison subsystems from different pre-existing systems may prove useful.

The next step is to assess the potential comparison systems for their similarity and applicability to the system under design and assure that the selected comparison systems include human engineering information such as human capabilities and limitations. The earlier that the systems are selected and the closer that they are in applicability to the system under design, the more usable they will be throughout the engineering process.

Sources:

7. section 1.2.1
9. pages 85-87

Collect HE Comparison Systems Evaluation Data

Using the selected comparison systems, extract human engineering data that may be utilized to direct the design of the system under consideration. The comparison system evaluation data collected will describe the systems selected via historical data, observational data, user data/feedback, and/or experimental data (based on prototypes, demos, and research) that may be useful in the planning and design of the proposed system. In addition, data may come from the selected systems by many techniques, including observations, interviews, questionnaires, activity analyses, critical incident studies, or accident investigations.

The comparison systems data may help estimate human performance, workload and other human engineering-related variables that will be used in requirements generation and verification or may be used more formally as a baseline that the new system must meet or exceed.

Define System Use Scenarios

From the human user's point of view, describe the events of the system mission (or missions) in detail, down to human tasks and sequences. Include the identification of mission phases, mission time scale and events external to (and their interactions with) the system in terms of system requirements and threat. Descriptions of the missions based on the operational requirements and the scenarios developed by the systems engineers should range from the typical, representative missions (possibly from previous systems) to the worst-case scenarios.

Scenarios selected should emphasize the impacts on the human operator/ maintainer, including performance, potential environmental effects and safety, and include both physical and cognitive tasks. Scenarios will be used in task analysis, requirements development and interface design, but may also be used for conducting simulations of human performance and workload. Before utilization, the systems engineers will approve the scenarios, as they are subsets of those created in the systems engineering process with the focus of the system use scenarios on the user.

Sources:

4. V2I2 section 1.1
5. section 6.1.4
7. sections 1.1.7, 1.2.2

Identify User Characteristics and KSAs (Knowledge, Skills and Abilities)

The more complex the system under design is, the more extensive the skills needed by potential operators and maintainers. User characteristics and KSAs (the characteristics, knowledge, skills and abilities required of the user to perform a function after training) should be established based on requirements and anticipated system performance, from resources such as the concept of operations (CONOPS) and the operational requirements document (ORD). "Characteristics" may be categorized as those factors that the human user possesses that may not be changed (e.g., anthropometric dimensions, eye color). KSAs can be trained or previously learned (cognitive, mechanical, sensory-motor and verbal skills and abilities, as well as acquired knowledge, etc.) and are based on the operational requirements and concepts to keep training to a realistic, affordable amount. They will, however, be updated/refined as the task analysis proceeds and as the scope of the system is refined. Training requires numerous resources and if training is required to meet a KSA, then it should be carefully considered in trade-offs and possibly minimized to reduce cost.

Characteristics and KSAs should be quantitative whenever possible and based on functions typically performed by humans and the details of the performance of specific functions or tasks in existing systems. As the characteristics and KSAs of the users are determined, it should not be the goal to have the performance plateau early in order to ensure ease-of-use with minimal training (i.e., do not limit performance of the users by designing towards a small learning curve). Once determined, the user characteristics and KSAs will be used throughout the process in steps such as generating requirements and establishing workload levels.

Sources:

7. section 1.2.8.1
8. pages 147-148
9. pages 43-44
16. pages 60-69

Identify Initial Characteristics and KSAs

In contrast to the User Characteristics and KSAs, the Initial Characteristics and KSAs are those that the user possesses when entering a system. Therefore, the difference between the Initial and User levels may be labeled as training. This may not, however, be applicable to the characteristics. As mentioned in the previous step, "characteristics" may be thought of as those factors that one possesses that are not changed, while the KSAs may be trained or learned. The "ending point" (user characteristics and KSAs) must be determined before the "starting point" (initial) due to the fact that training must make up the difference between the two and should be reasonable and achievable. The initial characteristics and KSAs will be used in determining the training and selection requirements, and the human engineering constraints placed on the system.

Sources:

8. pages 147-148
16. pages 60-69

Identify User Environment Characteristics

Determine the environments in which the system will operate for each of the operational scenarios. Both current and future or anticipated environments must be considered. All characteristics of environments for all types of conditions should be identified including natural and induced (in normal, unusual and emergency conditions).

Special emphasis should be placed on those characteristics that may be extreme in nature affecting performance and/or safety, including those that are not explicit. Some environmental characteristics that will affect the user include thermal control, illumination, vibration, movement, and noise control.

The conditions will then be analyzed for their effects on the users/operators. These characteristics will impact system components such as life support, operator exposure or duty limits, and other human performance-shaping factors.

Sources:

5. section 6.1.8
6. section 3.2.2.3
7. section 1.1.5
9. pages 49, 181-198

<u>Identify Environmental Effects</u>

Environmental effects on hardware, software and humans should be identified and assessed for impact on system performance and life-cycle processes based on the environmental characteristics of the conditions identified. The effects of some conditions may range from an inability to sense information to the possibility of physical injury. However, one must keep in mind that tolerance levels are inversely related to duration of the stress, so an operator may be exposed to unusually high levels of an environmental condition for a short period of time before causing any lasting effects. The effects should be identified and explained to a level of detail appropriate for the current stage of development, as this identification may be re-evaluated later in the process if the understanding of the environmental conditions evolves.

The effects will then be assessed to see if they will affect the necessary requirements in human and system performance and/or workload. Risks to human operators/ maintainers should also be identified by highlighting those effects that may be beyond human mental or physical tolerances.

Sources:

5. section 6.1.8
9. pages 181-198

Significant Products:

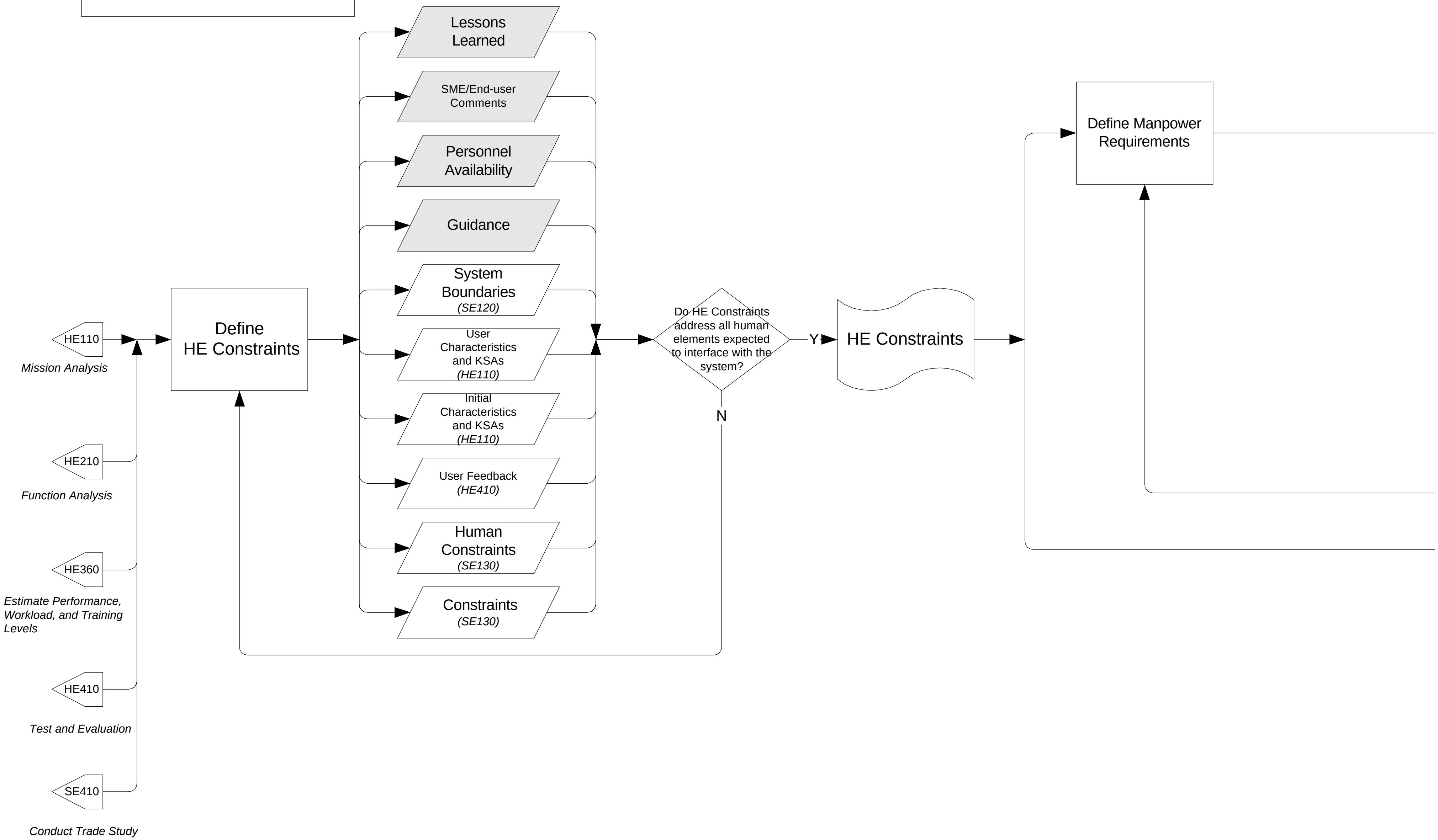
- Comparison Systems
  Includes Human Capabilities and Limitations.
- System Use Scenarios
  The scenarios will be approved by the Systems Engineering Team and should use terminology that will be understood by the reviewers. Scenarios may be in narrative or graphic format. Graphic formats include plots of system activities, functions, and events against time or location. The system use scenario will be used throughout the HE process to provide events/phases specific to those experienced by the system user.
- User Characteristics and KSAs
  Will be approved by the systems engineers
- Initial Characteristics and KSAs

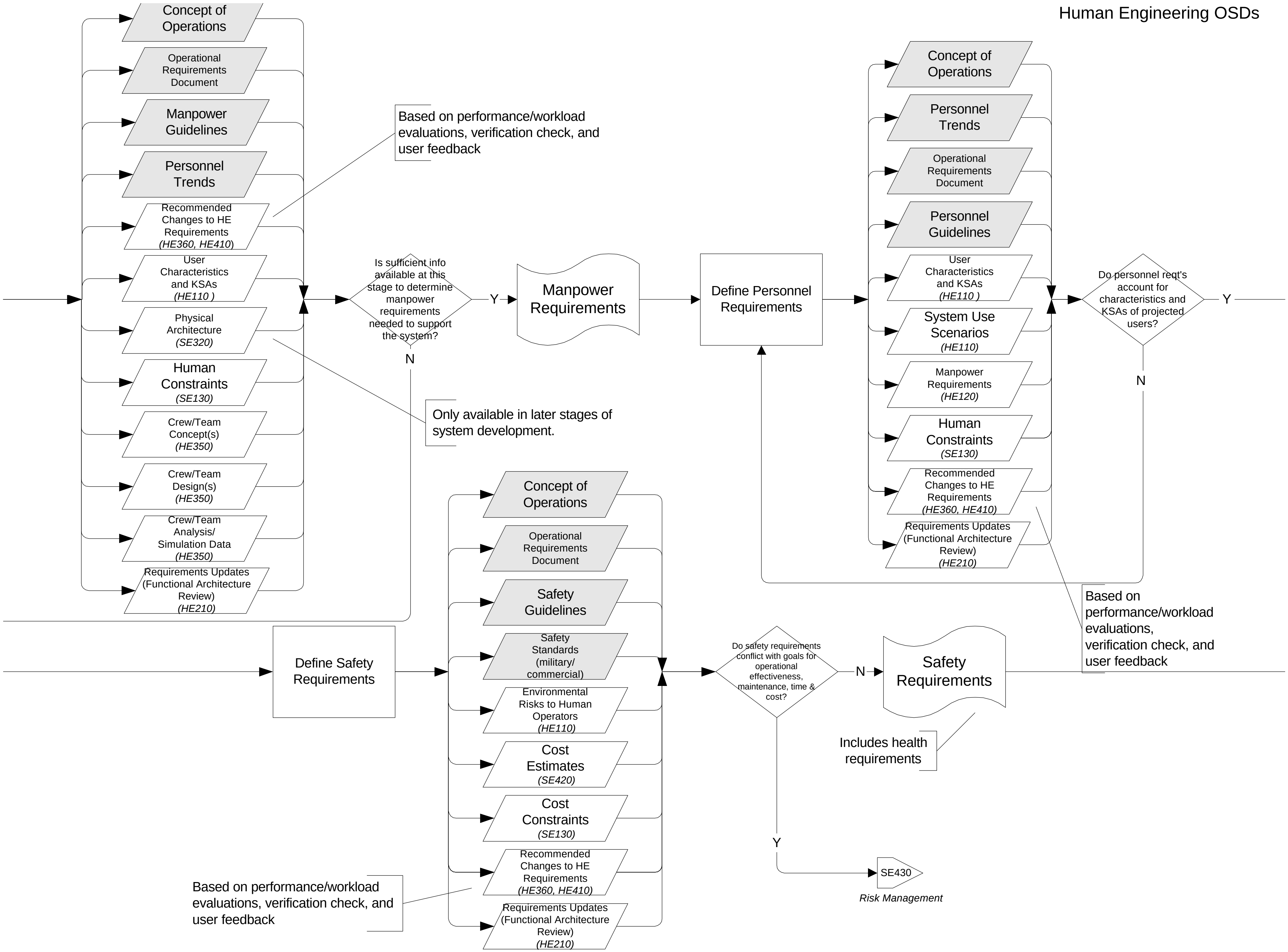
- Environmental Risks to Human Operators
  Some of the effects identified that may minimize risk of death, injury or acute chronic illness, disability, and/or reduced job performance.
- Environmental Effects

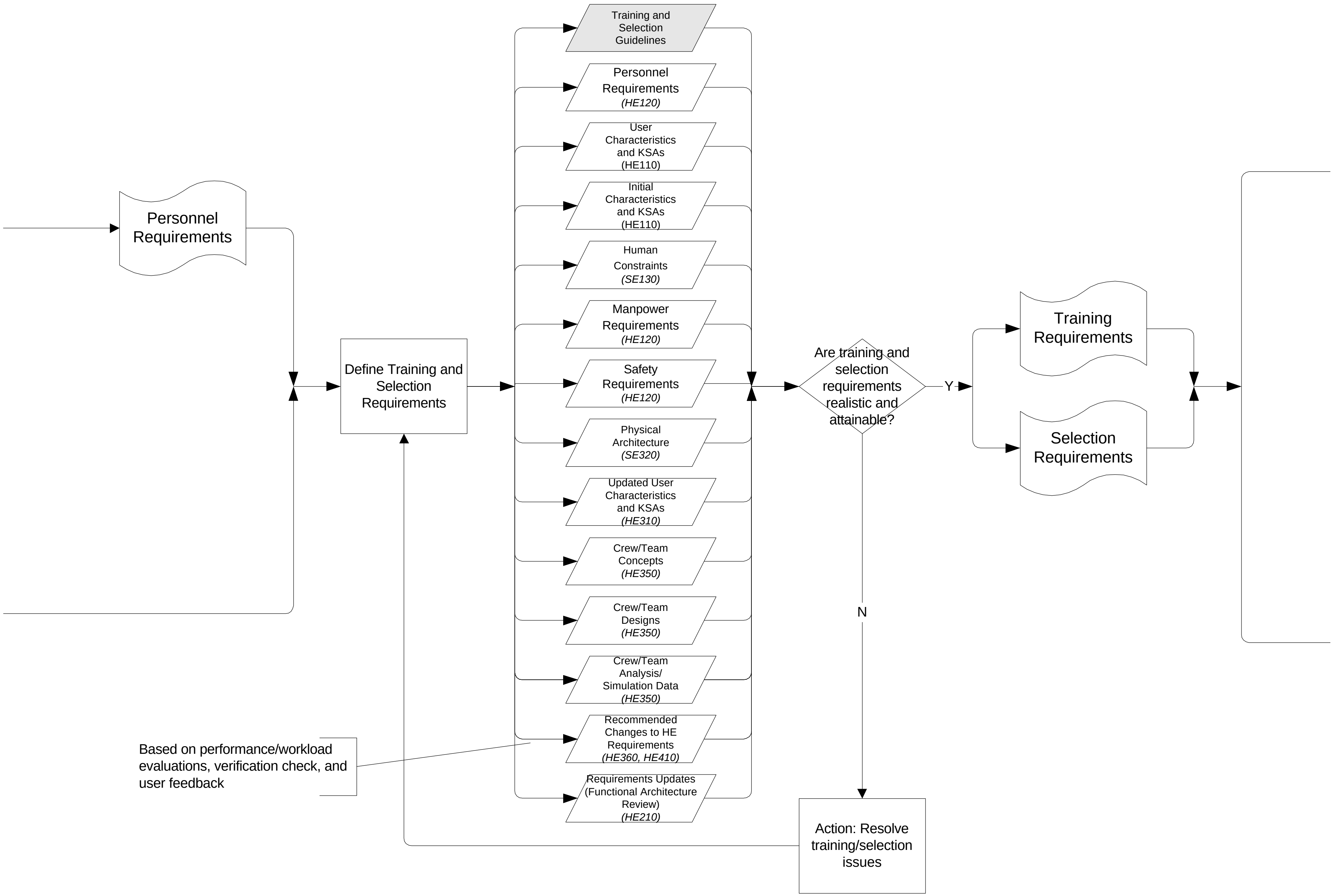
HE 120 – Develop Human Engineering Requirements

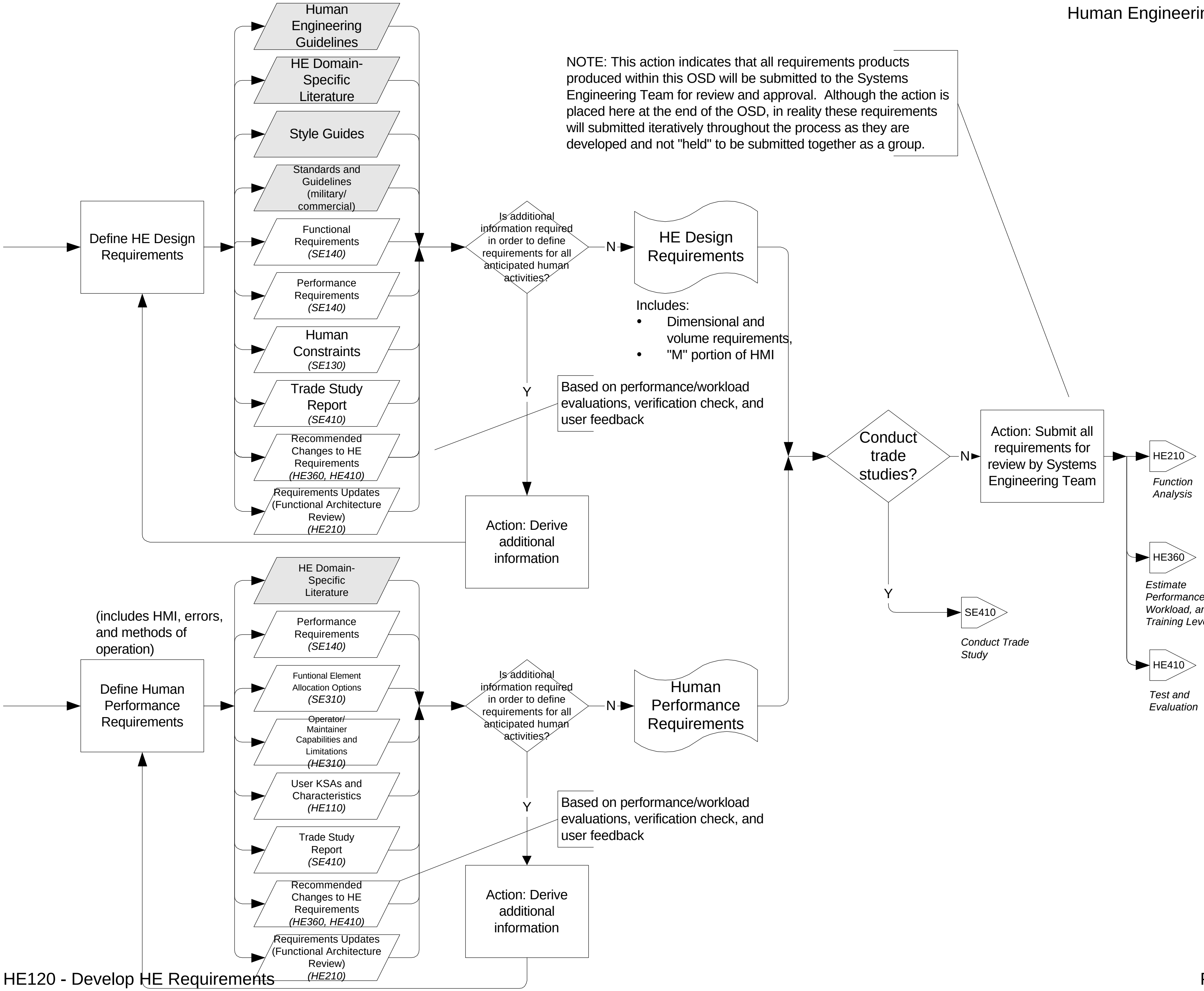
HE120 - Develop HE Requirements

LAST EDIT DATE: 3/1/00




Concept of Operations
Operational Requirements Document
Manpower Guidelines
Personnel Trends
Recommended Changes to HE Requirements (HE360, HE410)
User Characteristics and KSAs (HE110)
Physical Architecture (SE320)
Human Constraints (SE130)
Crew/Team Concept(s) (HE350)
Crew/Team Design(s) (HE350)
Crew/Team Analysis/ Simulation Data (HE350)
Requirements Updates (Functional Architecture Review) (HE210)
Based on performance/workload evaluations, verification check, and user feedback
Is sufficient info available at this stage to determine manpower requirements needed to support the system?
Y
N
Manpower Requirements
Only available in later stages of system development.
Define Personnel Requirements
Concept of Operations
Personnel Trends
Operational Requirements Document
Personnel Guidelines
User Characteristics and KSAs (HE110)
System Use Scenarios (HE110)
Manpower Requirements (HE120)
Human Constraints (SE130)
Recommended Changes to HE Requirements (HE360, HE410)
Requirements Updates (Functional Architecture Review) (HE210)
Do personnel reqt's account for characteristics and KSAs of projected users?
Y
N
Based on performance/workload evaluations, verification check, and user feedback
Define Safety Requirements
Concept of Operations
Operational Requirements Document
Safety Guidelines
Safety Standards (military/ commercial)
Environmental Risks to Human Operators (HE110)
Cost Estimates (SE420)
Cost Constraints (SE130)
Recommended Changes to HE Requirements (HE360, HE410)
Requirements Updates (Functional Architecture Review) (HE210)
Do safety requirements conflict with goals for operational effectiveness, maintenance, time & cost?
N
Safety Requirements
Includes health requirements
Y
SE430
Risk Management
Based on performance/workload evaluations, verification check, and user feedback


Personnel Requirements
Define Training and Selection Requirements
Training and Selection Guidelines
Personnel Requirements (HE120)
User Characteristics and KSAs (HE110)
Initial Characteristics and KSAs (HE110)
Human Constraints (SE130)
Manpower Requirements (HE120)
Safety Requirements (HE120)
Physical Architecture (SE320)
Updated User Characteristics and KSAs (HE310)
Crew/Team Concepts (HE350)
Crew/Team Designs (HE350)
Crew/Team Analysis/ Simulation Data (HE350)
Recommended Changes to HE Requirements (HE360, HE410)
Requirements Updates (Functional Architecture Review) (HE210)
Based on performance/workload evaluations, verification check, and user feedback
Are training and selection requirements realistic and attainable?
Y
N
Training Requirements
Selection Requirements
Action: Resolve training/selection issues


Define HE Design Requirements
Human Engineering Guidelines
HE Domain-Specific Literature
Style Guides
Standards and Guidelines (military/ commercial)
Functional Requirements (SE140)
Performance Requirements (SE140)
Human Constraints (SE130)
Trade Study Report (SE410)
Recommended Changes to HE Requirements (HE360, HE410)
Requirements Updates (Functional Architecture Review) (HE210)
Is additional information required in order to define requirements for all anticipated human activities?
N
Y
HE Design Requirements
Includes:
• Dimensional and volume requirements,
• "M" portion of HMI
Based on performance/workload evaluations, verification check, and user feedback
Action: Derive additional information
NOTE: This action indicates that all requirements products produced within this OSD will be submitted to the Systems Engineering Team for review and approval. Although the action is placed here at the end of the OSD, in reality these requirements will submitted iteratively throughout the process as they are developed and not "held" to be submitted together as a group.
Conduct trade studies?
N
Y
Action: Submit all requirements for review by Systems Engineering Team
HE210
Function Analysis
HE360
Estimate Performance, Workload, and Training Levels
HE410
Test and Evaluation
SE410
Conduct Trade Study
(includes HMI, errors, and methods of operation)
Define Human Performance Requirements
HE Domain-Specific Literature
Performance Requirements (SE140)
Funtional Element Allocation Options (SE310)
Operator/ Maintainer Capabilities and Limitations (HE310)
User KSAs and Characteristics (HE110)
Trade Study Report (SE410)
Recommended Changes to HE Requirements (HE360, HE410)
Requirements Updates (Functional Architecture Review) (HE210)
Is additional information required in order to define requirements for all anticipated human activities?
N
Y
Human Performance Requirements
Based on performance/workload evaluations, verification check, and user feedback
Action: Derive additional information

HE 120 – Develop Human Engineering Requirements

Narrative:

After identifying the characteristics of the operators and maintainers based on the mission requirements, the next step is to determine the intended users (and maintainers) of the system and identify and define the capabilities of these users and the criteria for their selection. Assess the feasibility and internal compatibility of the system requirements. Define the system's human and job/task requirements, manning, and training cost guidelines.

All of the requirements defined here may also be based on recommended changes determined later (used in subsequent passes to this group of tasks) that feed off performance/workload evaluations, verification checks, and user feedback. In addition, the requirements are based on the physical architecture developed in systems engineering (SE) available at later stages in system development.

<u>Define HE Constraints</u>

Given the definition of the system boundaries, determine what human engineering constraints placed on the system by project, enterprise, and external factors will impact design solutions. Constraints include cost and funding (for design as well as operation and maintenance), infrastructure, training limitations, manning availability, human capabilities, etc. The change of constraints over time (through both life cycle phases and operational phases) must be identified. Built from external limitations, most of the HE constraints come from the inherent limitations of humans in general (human-related specifications, standards and guidelines; human availability, recruitment and selection). The system developer should differentiate which are constraints and which can be changed based on trade studies.

Sources:

5. sections 6.1.2, 6.1.3, 6.1.15

<u>Define Manpower Requirements</u>

Identify the job tasks and associated workload including the determination of the number and mix of human resources (for example, a mix of military, DoD, civilian and contractor personnel) needed and available to staff, operate, maintain, support and provide training for all system elements across the required operating capabilities in the projected environment. The requirements will be based on personnel trends, guidelines and operational requirements and information about the crew/team concepts up to this point. However, they may alter significantly or be updated as performance and workload are evaluated and verified, and as user feedback is gathered.

Sources:

5. section 6.1.9.1
8. page 4
9. pages 71, 86

<u>Define Personnel Requirements</u>

Personnel factors include the aptitudes, knowledge, abilities, skill levels, experiences, physical constraints, staffing requirements, training programs necessary for the required skills, and force management policies (e.g. recruitment and retention) needed to execute the required tasks and system life cycle processes for the anticipated users. The requirements should be based on these factors, personnel trends, guidelines, operational requirements and information about the crew/team concepts up to this point; however, they should not be defined to a level of great detail at this stage because the requirements will change as system development proceeds.

Sources:

5. section 6.1.9.2
8. page 4
9. pages 49, 72, 280

<u>Define Safety Requirements</u>

Define the safety factors, including equipment/system design features, performance specifications and training, which reduce the potential for human or machine errors or failures that may cause accidental injury or death. Based on safety guidelines, military/commercial standards and identified risks to humans, these factors should be within the constraints of operational effectiveness, maintenance, time and cost throughout the equipment/system life cycle. However, they may not be defined to great detail during the first pass through this process because they will change as system development proceeds. The requirements must be regularly checked against conflicting goals for operational effectiveness, maintenance, time and cost.

Sources:

5. section 6.1.9.5
8. pages 4
9. pages 71, 280

<u>Define Training and Selection Requirements</u>

The number and types of users selected to operate/maintain a system directly impact the life cycle costs. The more complex the system is, the greater the number and complexity of skills required, and therefore the more stringent the selection requirements must be in terms of personnel qualifications (education, skills, training).

The difference between the knowledge, skills and abilities required (the user KSAs) and the basic knowledge, skills and abilities available (the initial KSAs) must be accommodated by training. Identify and define the required instruction, education, on-the-job or team training and applied exercises to conduct the training needed. Include measurable and specific performance levels for acquiring and retaining knowledge, skills and abilities necessary to prepare personnel to operate, maintain and support the system life cycle. Also include in the requirements: training curricula, materials, facilities, devices, tools/techniques, simulators, etc. System components, like the training requirements, must be defined in the required operational environment at the specified levels of performance throughout in order to be fully utilized.

Sources:

5. section 6.1.9.3
8. page 4, 148
9. pages 72, 280

Define Human Engineering Design Requirements

Define the design requirements that the system must satisfy to adequately support the human operators and maintainers. Examples include supporting the physical, cognitive, motor, sensory, and visual activities of the humans based on human engineering guidelines and literature. Define the requirements the system must satisfy to adequately support the functions, jobs and tasks that the human operators and maintainers will be expected to perform. Job/task requirements (if available) also include the support of situation awareness, prediction of future system states or performance, and cognitive support such as that necessary for human takeover in the event of automation failure.

Sources:

5. sections 6.1.9.4, 6.1.14, 6.1.15
7. section 3.1.15

Define Human Performance Requirements

Human performance requirements will be derived from each of the functions allocated to the human and the "User KSAs" (the knowledge skills and abilities that the user will need to possess after training, but before operating the system). Human performance requirements may include requirements for human-machine interfaces (based on the system-level performance requirements, but only for the functions performed by humans) based on performance criteria associated with functions and sub-functions.

The performance requirements will be the standards of successful performance, tempo of operations, and tactical objectives and will determine how well the functions must be performed to satisfy the measures of effectiveness. Include qualitative (how well), quantitative (how much, capacity), and timeline (how often, how long) requirements. The allocated functions tell the human engineer what it is that the operator must do (including the context) and the KSAs indicate how the operator must do it (the technique). Adding a testable parameter, which is a consideration in requirements definition, yields a measurable human performance requirement. In some cases, the human performance requirement will provide feedback to help refine or develop new KSAs.

Sources:

5. section 6.1.11, 6.1.16
7. sections 1.1.6, 1.2.5.1
9. page 71

Conduct Trade Studies

All of the requirements developed in this OSD are submitted to the systems engineers for review of concurrence with the SE requirements and to examine the possibility of conducting trade studies to analyze and balance conflicting requirements. Trade studies are conducted to help select between competing alternatives to support customer needs, system effectiveness, or lifecycle costs within acceptable levels of risk. Tradeoffs are more important to human factors engineers due to the specificity of requirements necessary at all levels. Examples include the level of automation provided by a system, selection versus the degree of training, and colors of an interface.

Tradeoffs should be done by providing quantitative data on human performance for alternative designs. Trade studies are necessary when the decision will affect manning, skill levels, training, safety, and/or comfort and satisfaction.
Sources:
5. section 6.7.6
9. pages 50, 281-286

<u>Submit all requirements for review by systems engineers</u>
This action indicates that all human engineering requirements produced within this OSD will be submitted to the systems engineers for review and approval. Although the action is placed here at the end of the OSD, in reality these requirements will be submitted iteratively throughout the process as they are developed and not "held" to be submitted together as a group.

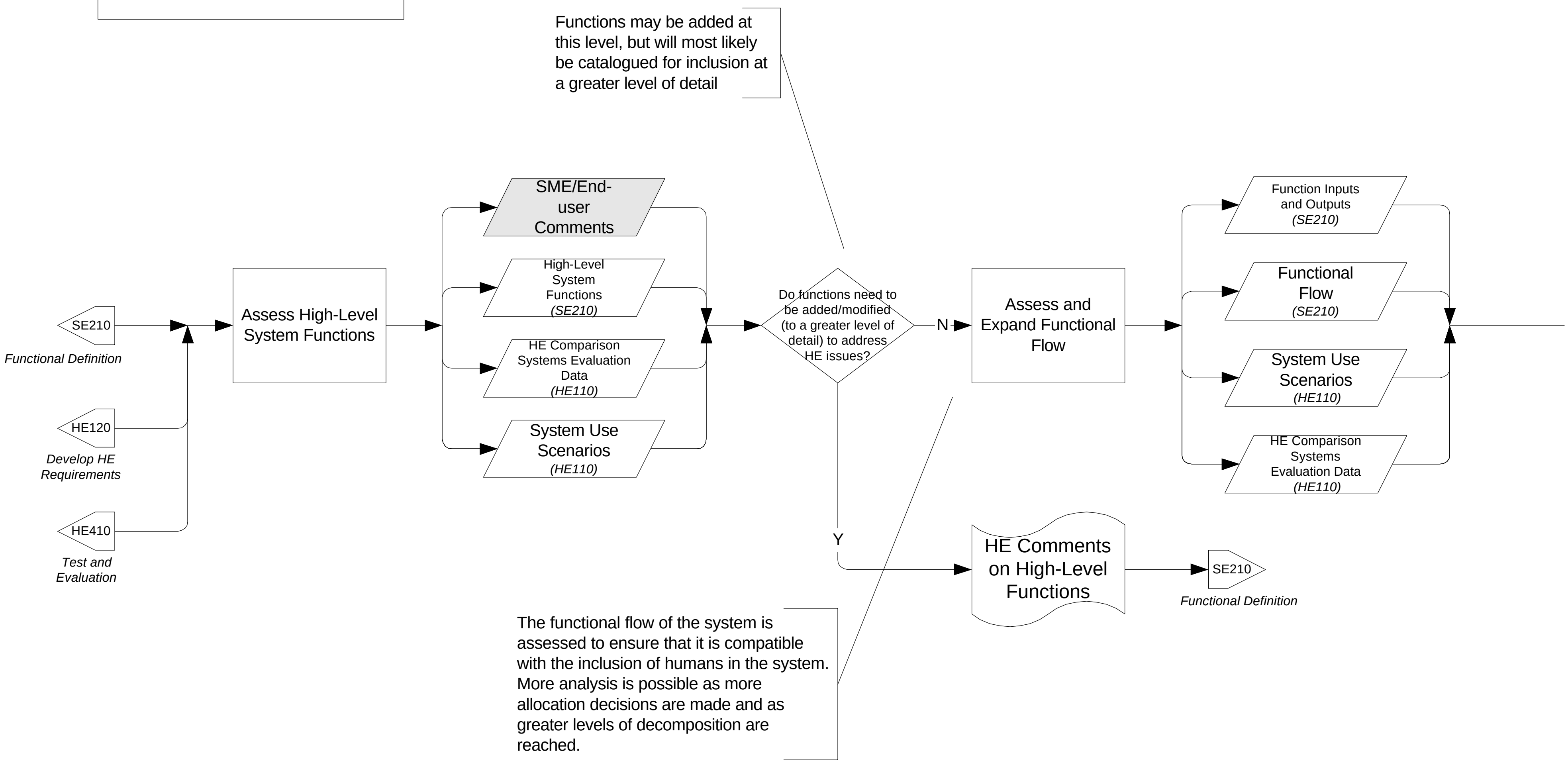
Significant Products:

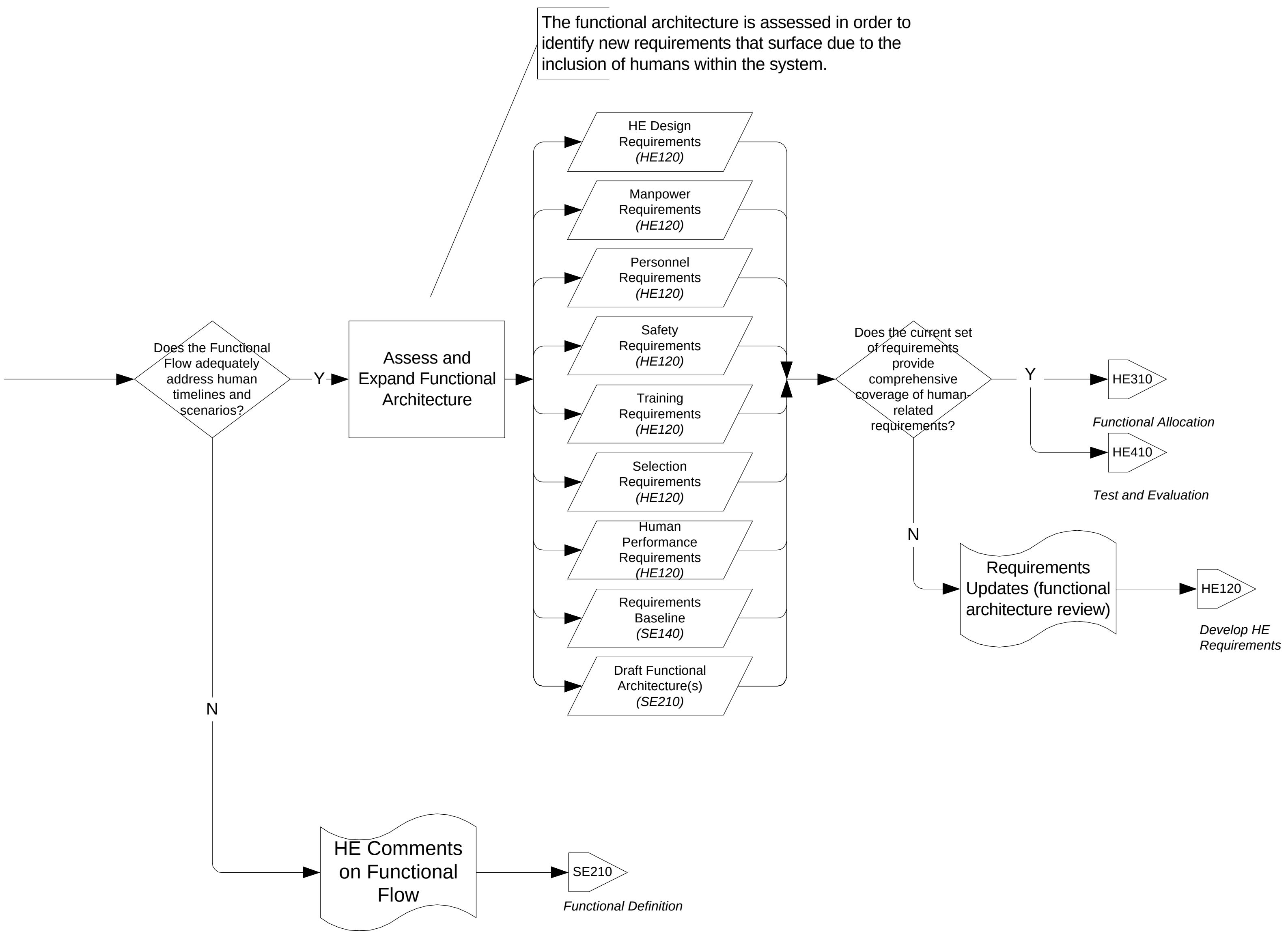
- HE Constraints
- Manpower Requirements
- Personnel Requirements
  The personnel requirements are the qualitative attributes of the manpower requirements
- Safety Requirements
  Includes Health Requirements
- Training Requirements
- Selection Requirements
- Human Engineering Design Requirements
  These requirements include but are not limited to human–machine interface guidelines and requirements, operator and maintainer duty cycle requirements, and overall design of the set of tasks assigned to individual operators or maintainers. The requirements will be used in the verification of the concepts and designs that will be produced. These are the M portion of HMI and includes dimensional and volume requirements.
- Human Performance Requirements
  Human performance requirements will be a combination of the functions allocated to the human (from SE 310) and the KSAs. The allocated functions tell the Human Engineer what it is that the operator must do (the context) and the KSAs indicate the technique. Adding a testable parameter yields a measurable human performance requirement. In some cases, the human performance requirement will provide feedback to help refine of develop new KSAs. Includes HMI, errors, and methods of operation.

HE 210 – Function Analysis

HE210 - Function Analysis

LAST EDIT DATE: 3/1/00





The functional architecture is assessed in order to identify new requirements that surface due to the inclusion of humans within the system.
Does the Functional Flow adequately address human timelines and scenarios?
Y
N
Assess and Expand Functional Architecture
HE Design Requirements (HE120)
Manpower Requirements (HE120)
Personnel Requirements (HE120)
Safety Requirements (HE120)
Training Requirements (HE120)
Selection Requirements (HE120)
Human Performance Requirements (HE120)
Requirements Baseline (SE140)
Draft Functional Architecture(s) (SE210)
Does the current set of requirements provide comprehensive coverage of human-related requirements?
Y
N
HE310
Functional Allocation
HE410
Test and Evaluation
Requirements Updates (functional architecture review)
HE120
Develop HE Requirements
HE Comments on Functional Flow
SE210
Functional Definition

HE 210 – Function Analysis

Narrative:

Assess the system's functional architecture – the sequence of operations or events to turn inputs into desired outputs – for the inclusion of humans and compare the potential alternatives. Although the system may be broken into functions, tasks, and subtasks to be performed, no allocation to particular system components takes place at this point. This phase and the two following phases may be initially performed at a high system-level with little function decomposition or consideration for a design solution, but these stages must be reiterated at a level of greater detail as the design progresses and the inclusion of humans becomes more complex.

This analysis in the human engineering environment is basically a three step process including the assessment of the system-level functions, the functional flow, and then the functional architecture for the inclusion of humans. Expansion of the flow and architecture is encouraged if the coverage is deemed insufficient by the human engineers (a task that is performed in conjunction with the systems engineers through recommendations and comments).

<u>Assess High-Level System Functions</u>

The top-level system functions are reviewed and assessed for each scenario identified and for each mission phase (pre-operational, normal operations, contingency, re-supply, maintenance, and termination). Any required associated functions involving humans, or functions or requirements that are necessitated by the inclusion of humans in the system, are identified along with the context of the functions (inputs and outputs) to accomplish the objectives. Refine, or define to greater detail, the system functions identified in the *Mission Analysis* that may include humans. Identify missing functions, and assess the order of functions or the frequency of functions based on requirements identified for each function. Functions may be changed due to information uncovered in previous steps of the *Requirements Analysis* process. New human engineering-related functions may be added at this level, but will most likely be catalogued for inclusion at a greater level of detail.

Sources:

4. V2I2 section 2, pages 13-15
7. sections 1.1.4, 1.2.3, 1.2.4

<u>Assess and Expand Functional Flow</u>

The functional flow of the system is assessed and expanded to ensure that it is compatible with the inclusion of humans in the system, which includes arrangements of functions, sequential relationships and behaviors. The flow may be more easily assessed by including a simulation in functional models. Additional analysis is possible as more allocation decisions are made and as greater levels of decomposition are reached. Products may be shown in functional flow diagrams (also known as functional block diagrams, functional flows, and functional flow block diagrams) and/or sequence and timing diagrams, and the analysis of functional flow should also include the data to be exchanged, frequency of functions, missing functions and order of functions.

Sources:
4. V2I2 sections 2.1-2.7, pages 17-42
5. section 6.3.2.1-5
7. section 1.2.4.2
9. pages 93-97

<u>Assess and Expand Functional Architecture</u>

The functional architecture of a system shows the contents and its construction and is defined at a level of detail appropriate for the current phase of development, initially a top-level functional view. The functional architecture, developed by the systems engineers, is assessed in order to identify new and lower-level functional requirements that surface due to the inclusion of humans within the system.

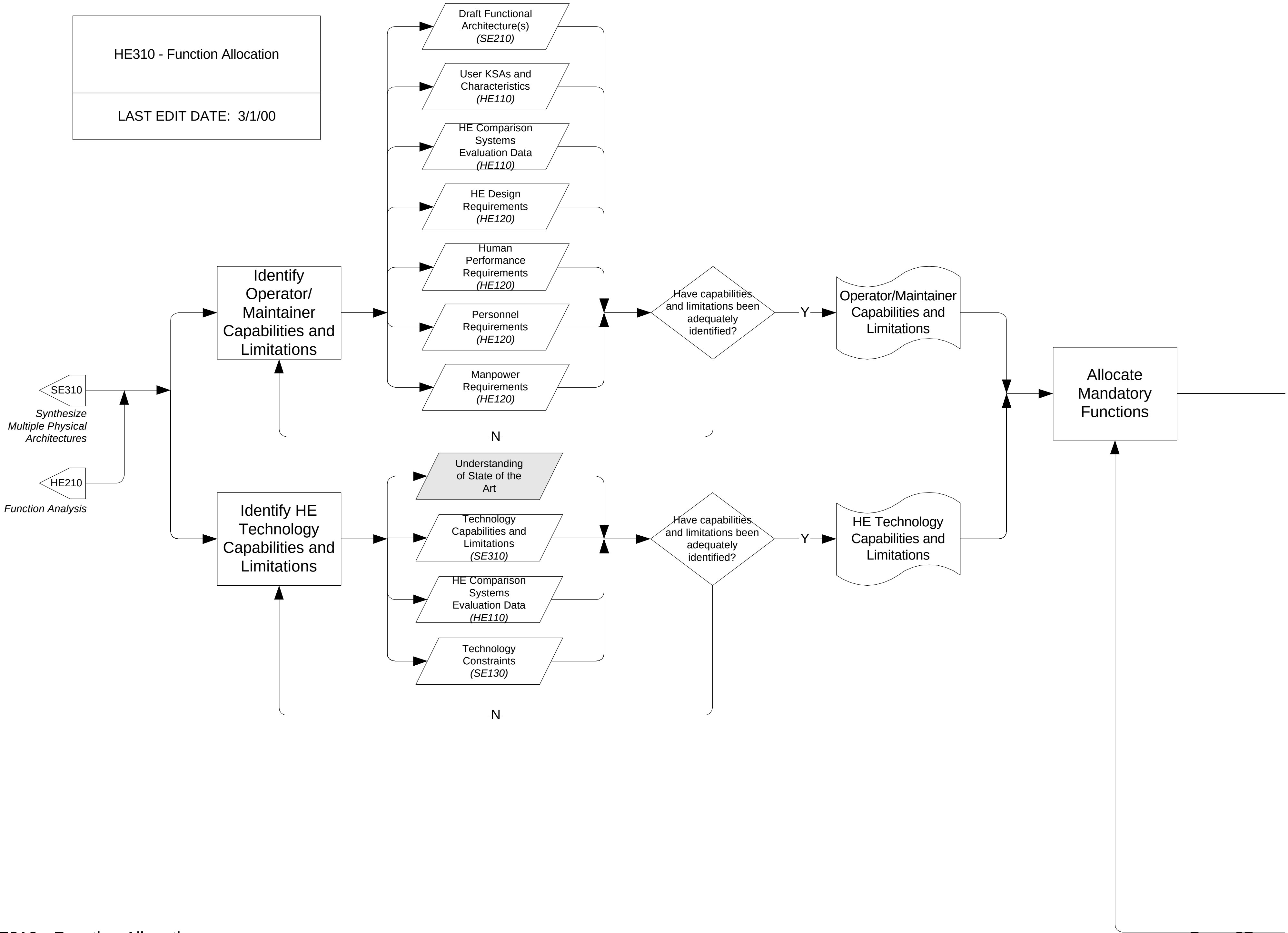
The architecture should include traceability to the human engineering-related requirements produced in the previous OSD. Updates to the human engineering requirements are produced based on a review of the draft functional architecture produced by the systems engineers if the current set does not adequately address human functions.

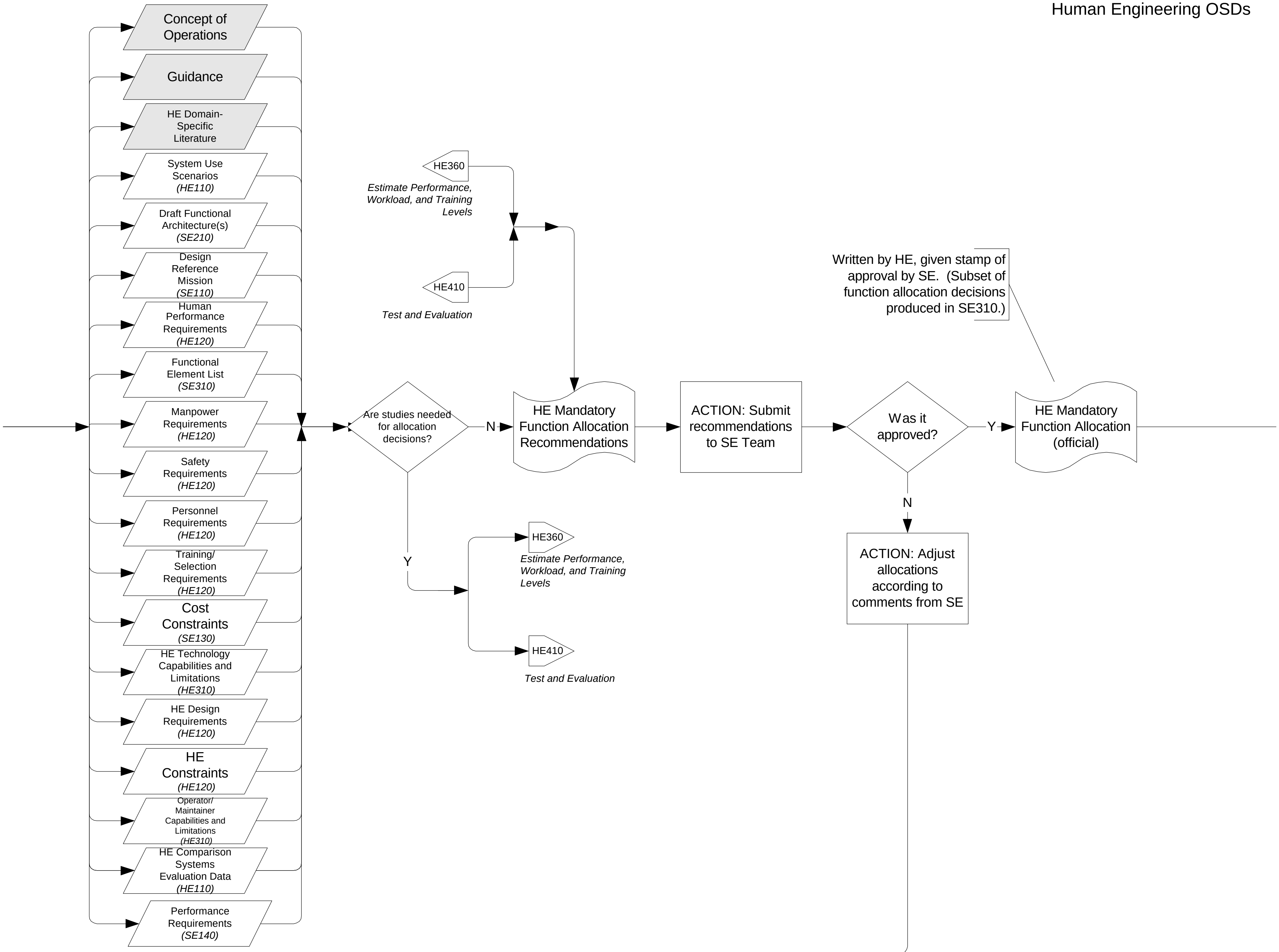
Sources:
5. section 6.3.3, 6.5.18

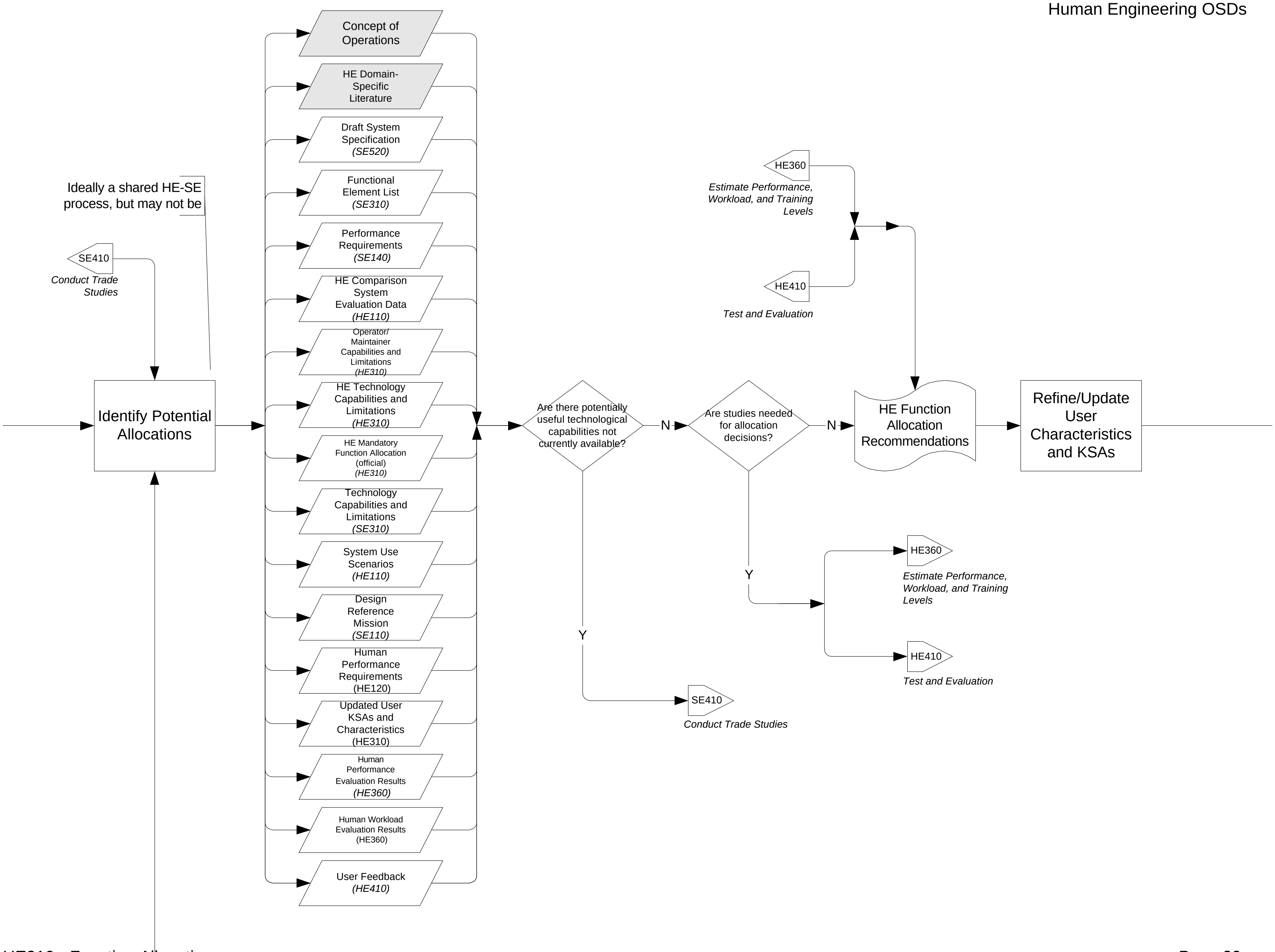
Significant Products:

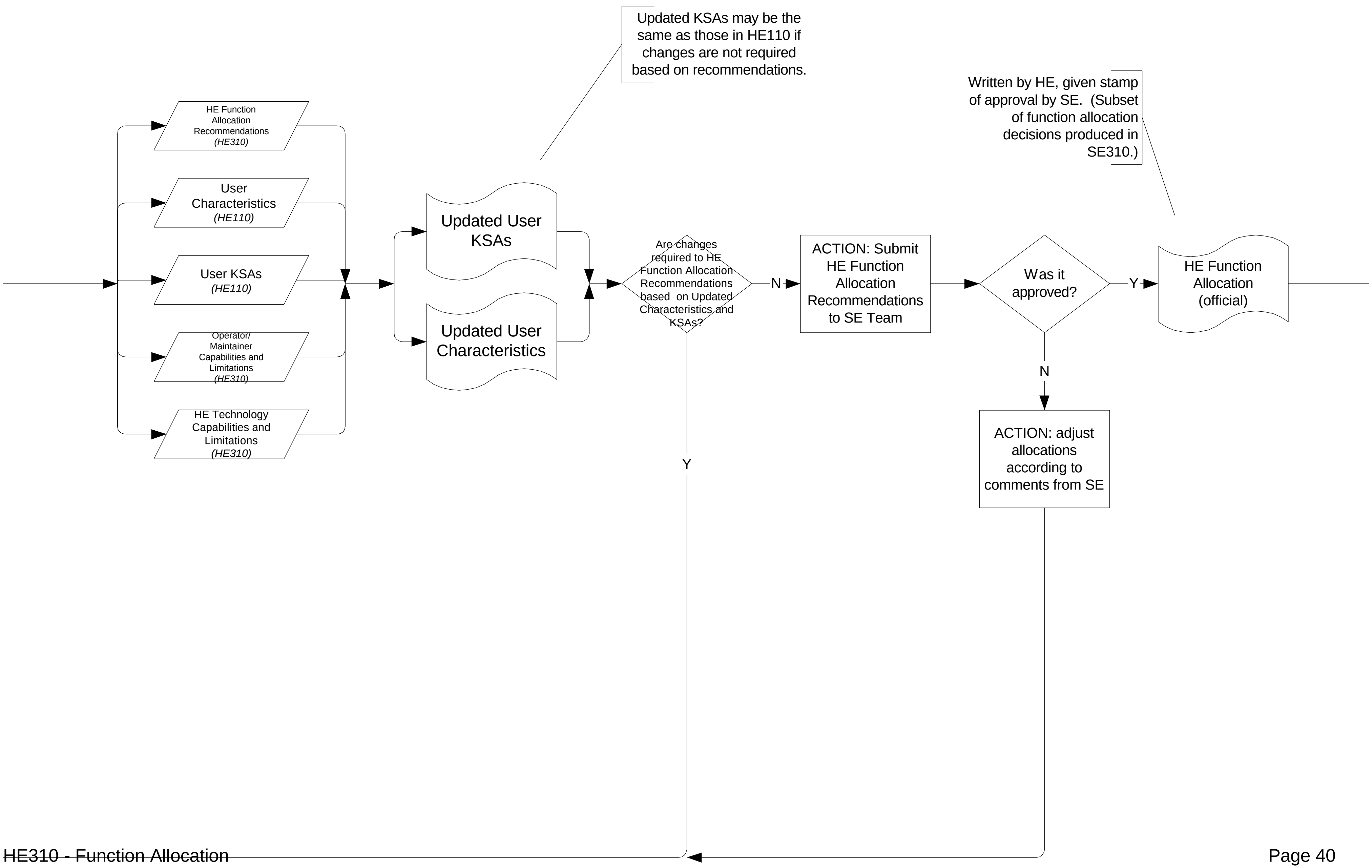
- HE Comments on Top-Level Functions
- HE Comments on Functional Flow
  When the functional flow has been found to be inadequate with respect to human-related issues, HE comments are produced and will be used in Functional Definition (SE210) as information required in producing Functional Flow. The comments will be in a format that is usable and understandable by the SE team.
- Requirements Updates
  All HE requirements developed earlier are revised to address more detailed function analysis. The requirements are for use in the allocation of mandatory and other functions.

HE 310 – Function Allocation

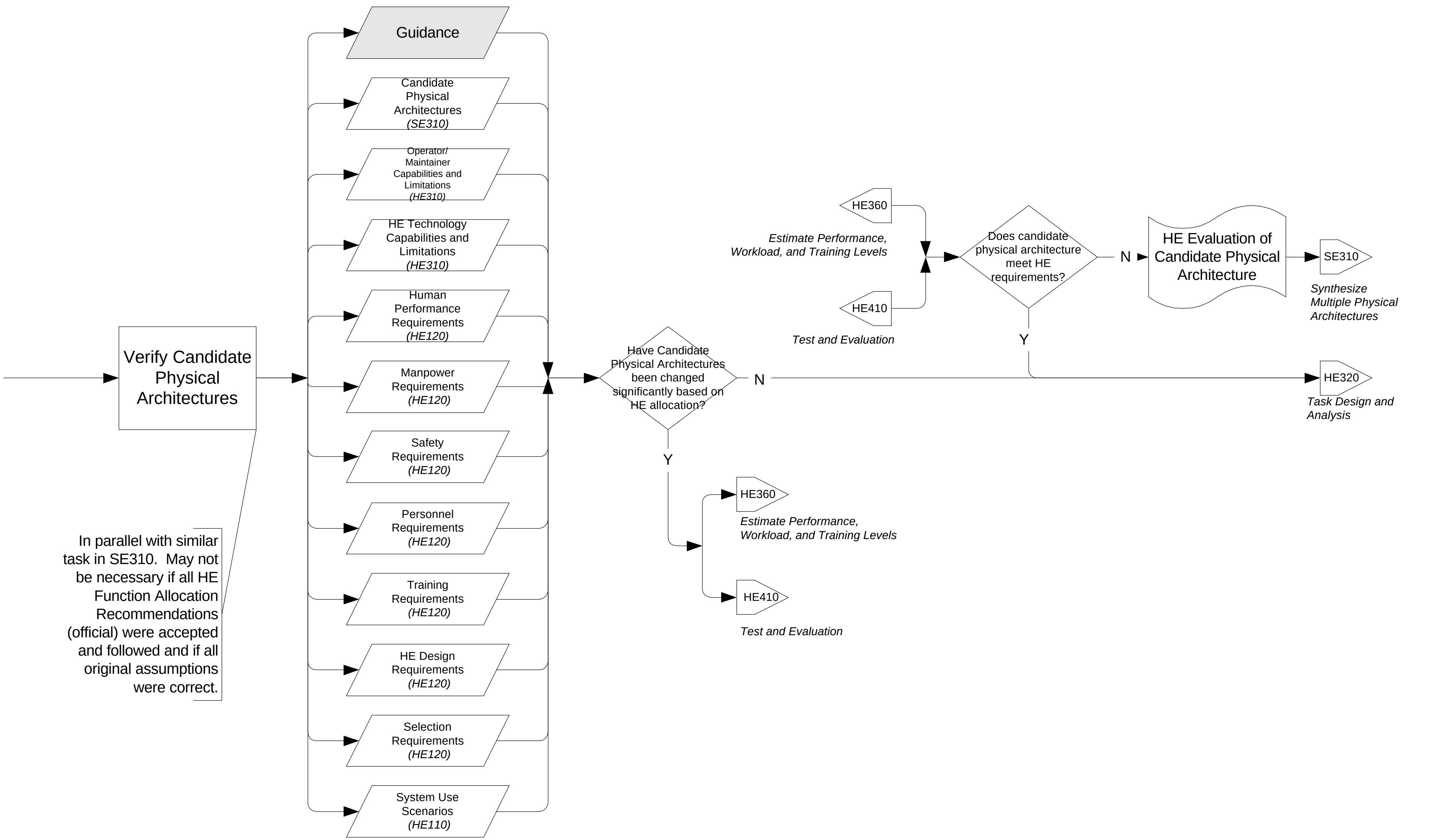

HE310 - Function Allocation
LAST EDIT DATE: 3/1/00
SE310
Synthesize Multiple Physical Architectures
HE210
Function Analysis
Identify Operator/ Maintainer Capabilities and Limitations
Draft Functional Architecture(s) (SE210)
User KSAs and Characteristics (HE110)
HE Comparison Systems Evaluation Data (HE110)
HE Design Requirements (HE120)
Human Performance Requirements (HE120)
Personnel Requirements (HE120)
Manpower Requirements (HE120)
Have capabilities and limitations been adequately identified?
Y
N
Operator/Maintainer Capabilities and Limitations
Identify HE Technology Capabilities and Limitations
Understanding of State of the Art
Technology Capabilities and Limitations (SE310)
HE Comparison Systems Evaluation Data (HE110)
Technology Constraints (SE130)
Have capabilities and limitations been adequately identified?
Y
N
HE Technology Capabilities and Limitations
Allocate Mandatory Functions


Concept of Operations
Guidance
HE Domain-Specific Literature
System Use Scenarios (HE110)
Draft Functional Architecture(s) (SE210)
Design Reference Mission (SE110)
Human Performance Requirements (HE120)
Functional Element List (SE310)
Manpower Requirements (HE120)
Safety Requirements (HE120)
Personnel Requirements (HE120)
Training/ Selection Requirements (HE120)
Cost Constraints (SE130)
HE Technology Capabilities and Limitations (HE310)
HE Design Requirements (HE120)
HE Constraints (HE120)
Operator/ Maintainer Capabilities and Limitations (HE310)
HE Comparison Systems Evaluation Data (HE110)
Performance Requirements (SE140)
HE360
Estimate Performance, Workload, and Training Levels
HE410
Test and Evaluation
Are studies needed for allocation decisions?
N
Y
HE Mandatory Function Allocation Recommendations
ACTION: Submit recommendations to SE Team
Was it approved?
Y
N
HE Mandatory Function Allocation (official)
Written by HE, given stamp of approval by SE. (Subset of function allocation decisions produced in SE310.)
ACTION: Adjust allocations according to comments from SE
HE360
Estimate Performance, Workload, and Training Levels
HE410
Test and Evaluation


Ideally a shared HE-SE process, but may not be
SE410
Conduct Trade Studies
Identify Potential Allocations
Concept of Operations
HE Domain-Specific Literature
Draft System Specification *(SE520)*
Functional Element List *(SE310)*
Performance Requirements *(SE140)*
HE Comparison System Evaluation Data *(HE110)*
Operator/ Maintainer Capabilities and Limitations *(HE310)*
HE Technology Capabilities and Limitations *(HE310)*
HE Mandatory Function Allocation (official) *(HE310)*
Technology Capabilities and Limitations *(SE310)*
System Use Scenarios *(HE110)*
Design Reference Mission *(SE110)*
Human Performance Requirements (HE120)
Updated User KSAs and Characteristics (HE310)
Human Performance Evaluation Results *(HE360)*
Human Workload Evaluation Results (HE360)
User Feedback *(HE410)*
Are there potentially useful technological capabilities not currently available?
N
Y
SE410
Conduct Trade Studies
Are studies needed for allocation decisions?
N
Y
HE360
Estimate Performance, Workload, and Training Levels
HE410
Test and Evaluation
HE360
Estimate Performance, Workload, and Training Levels
HE410
Test and Evaluation
HE Function Allocation Recommendations
Refine/Update User Characteristics and KSAs



Updated KSAs may be the same as those in HE110 if changes are not required based on recommendations.
Written by HE, given stamp of approval by SE. (Subset of function allocation decisions produced in SE310.)
HE Function Allocation Recommendations (HE310)
User Characteristics (HE110)
User KSAs (HE110)
Operator/ Maintainer Capabilities and Limitations (HE310)
HE Technology Capabilities and Limitations (HE310)
Updated User KSAs
Updated User Characteristics
Are changes required to HE Function Allocation Recommendations based on Updated Characteristics and KSAs?
N
Y
ACTION: Submit HE Function Allocation Recommendations to SE Team
Was it approved?
Y
N
HE Function Allocation (official)
ACTION: adjust allocations according to comments from SE


Verify Candidate Physical Architectures
In parallel with similar task in SE310. May not be necessary if all HE Function Allocation Recommendations (official) were accepted and followed and if all original assumptions were correct.
Guidance
Candidate Physical Architectures (SE310)
Operator/ Maintainer Capabilities and Limitations (HE310)
HE Technology Capabilities and Limitations (HE310)
Human Performance Requirements (HE120)
Manpower Requirements (HE120)
Safety Requirements (HE120)
Personnel Requirements (HE120)
Training Requirements (HE120)
HE Design Requirements (HE120)
Selection Requirements (HE120)
System Use Scenarios (HE110)
Have Candidate Physical Architectures been changed significantly based on HE allocation?
N
Y
HE360
Estimate Performance, Workload, and Training Levels
HE410
Test and Evaluation
Does candidate physical architecture meet HE requirements?
HE Evaluation of Candidate Physical Architecture
SE310
Synthesize Multiple Physical Architectures
HE320
Task Design and Analysis

HE 310 – Function Allocation

Narrative:

Function allocation is the task of assigning functions to hardware, software, humans or a combination thereof. The allocation process is generally a combination of quantitative and other less formal techniques. The first functions and decisions to be allocated are those having specific, mandatory allocation requirements between humans and machines.

The allocations are derived from system requirements, scenarios, performance requirements, human capabilities or other factors that are identified first and serve as constraints for the allocation decisions. Some functions or decisions will be required to be performed or made by hardware or software components of the system or by humans, possibly with the assistance of other system components in order to meet system requirements. These functions are the first to be allocated. The allocation of these mandatory allocated functions and decisions may then logically require that other functions or decisions be allocated to a specific portion of the system. The remaining functions are then allocated, primarily using judgment as guidance for the decisions. The allocations are then compared with the system-level physical architecture for congruence.

<u>Identify Operator and Maintainer Capabilities and Limitations</u>

Identify the characteristics, frequency, and distribution of the capabilities and limitations of the potential operator, user, and maintainer (expected populations) based on the function analysis and a review of tasks in similar systems. With respect to surface combatant design, manpower must be assessed by naval rating (or similar format) and rating attributes must be adaptable to reflect future populations.

Capabilities should focus on those unique to humans like signal detection in noise or decision making, and the results should be in quantitative terms if possible. Information on functions performed by humans is necessary with a focus on those functions that humans can perform very well and those that are difficult. Estimates of capabilities should be in terms of load, accuracy, and/or rate. Capabilities will be used to determine allocation decisions and will be utilized later for operator information requirements and interface control/display design requirements. This data may also help in the assignment of functions during the mandatory allocation process.

Sources:

4. V2I2 section 3.3
6. section 3.2.1.1.2
9. page 101

<u>Identify HE Technology Capabilities and Limitations</u>

Determine the extent to which available techniques meet technical requirements and technology availability (or ready date). Areas of technological influence in human engineering may include human computer interaction, decision support systems, and human performance models. Data on the state-of-the-art performance capabilities are needed for the functional allocation that will follow. Identify the potential for hardware and software to perform the system's functions and the external constraints of the technology base for the present and anticipated implementation time. The ability of the technology to perform, availability, cost, and compatibility are among the factors that must be addressed. Potential obstacles to technology insertion and acceptance, such as confidence in technology or information, compatibility with operator and maintainer expectations, training, or experience, must be identified. These forecasts will be based on an understanding of the current state of the art as well as technical information about existing and/or comparison systems.

Sources:

5. section 6.1.3
6. section 3.2.1.2
7. section 1.4.6.8
9. page 101

<u>Allocate Mandatory Functions</u>

The functional allocation, or assigning of functions to hardware, software, humans or a combination thereof, is only as good as the functional analysis and any accompanying function descriptions. For example, one unfavorable technique is the machine-based allocation ("techno-centered"), that allocates to the humans the functions that are leftover after the allocation to machines. What remains are gaps and under-loaded operators as opposed to a system of human operation with technological complements. Allocation decisions should be made so as to maximize total system performance and effectiveness. Functions identified are checked against constraints (e.g. legalities, guidance, role-of-humans statement, safety) to produce mandatory allocations.

The allocation of some functions will be predetermined by constraints established in the *Mission Analysis* or *Requirements Analysis* stages of design and therefore mandatory. Based on the capabilities and limitations of future operators, the performance of hardware and software, other identified mandatory allocation requirements, and additional external factors, allocate functions and decisions to the humans, equipment (hardware and software), or combinations to account for mandatory function and decision allocations. Compare the current allocation of functions to the allocation within comparison systems throughout the allocation process. Use the comparison to estimate the performance and other characteristics of the current allocation. The allocation is not a discrete event, but will be revisited throughout as the design progresses and the constraints evolve.

Sources:

1. section 2.3.3.3, pages 35-36
2. pages 334-335
3. pages 42-43
4. V2I2 section 3.4
5. section 6.5.1
6. sections 3.2.1.1, 3.2.1.1.3
7. section 1.3.2
9. pages 101-103

Submit Recommendations to SE Team

The allocation recommendations written by the human engineers are submitted to the systems engineers for a check in consistency and then a stamp of approval. The human engineering function allocation is a subset of function allocation decisions that are produced in SE310. Recommendations to the systems engineers should use terminology that will be understood by the reviewers.

Identify Potential Allocations

Identify potential alternate options and strategies for the allocation of functions not yet allocated. Allocations of the remaining (non-mandatory functions) may be made to hardware, software, humans or a combination. The allocation may be static or dynamic, changing with operational conditions, workloads, or mission priorities. The allocation will be made to whichever resource is most capable for that point in time. Allocation of mission-critical functions during the primary mission phase should take priority, followed by other primary mission functions and functions from other mission phases. Options should be based on component performance and a variety of other criteria, and ideally, a shared human engineering and systems engineering process.

The process is not very precise and may be based on a judgement in criteria and weights. Additionally, it will not be done once, but may evolve as criteria change (technological changes, software and hardware). For those that could be performed by either human or technology, provide descriptions and establish weighting criteria for comparison. Criteria are ranked and then rated and the ratings are multiplied by the weights and summed leaving the alternative with the highest score to be chosen. Include an assessment of the capability of future hardware and software technology, as well as humans, to assume roles that could only be allocated to humans previously.

Sources:

1. section 2.3.3.3, pages 35-36
2. pages 334-336
5. section 6.5.1
7. sections 1.3.6, 1.3.7
9. pages 101-103

Refine/Update User KSAs

Given the current functional architecture and allocation decisions, refine the previous estimates of the KSAs (knowledge, skills, and abilities) that will be required of the system operators and maintainers for each function identified in the mission scenario.

Sources:

4. V2I2 section 3.3
6. section 3.2.1.1.2
7. section 1.2.8.1
8. pages 147-148
9. pages 43-44

Submit HE Function Allocation Recommendations to SE Team

Allocation recommendations should be submitted to the systems engineers for concurrence with the overall allocation objectives and requirements, and should utilize terminology that will be understood by the reviewers.

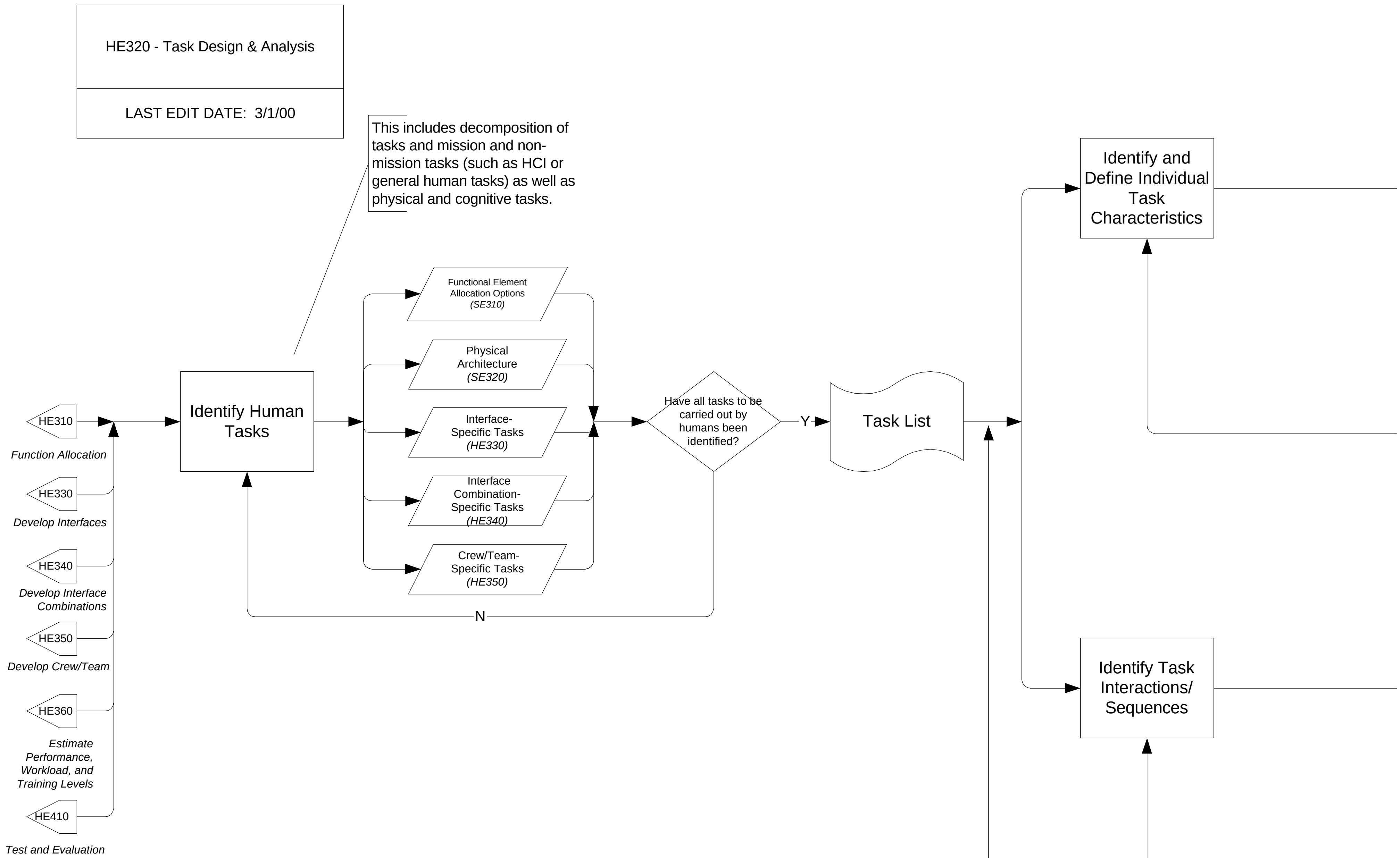
Verify Candidate Physical Architecture

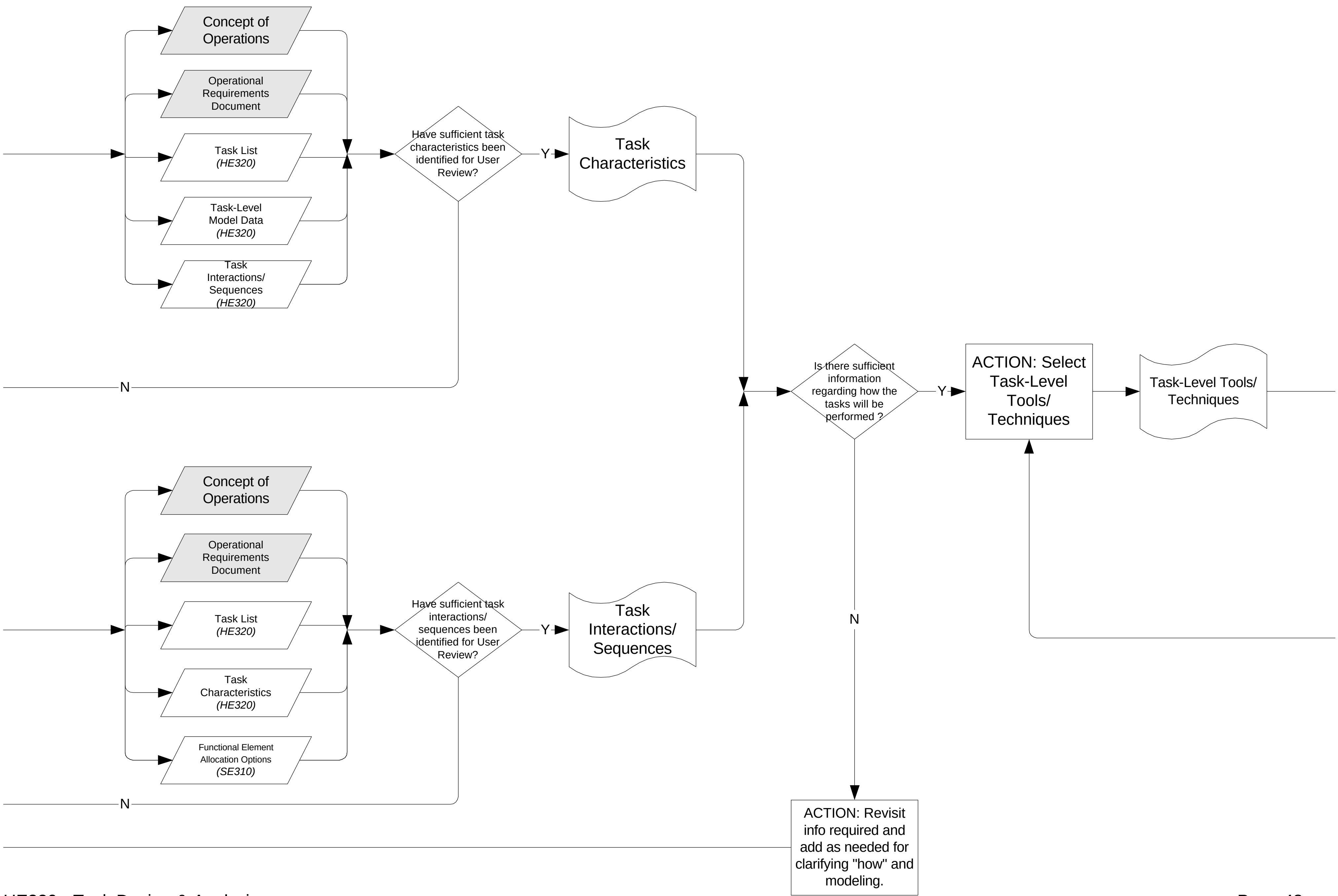
The allocation of functions is compared to the Candidate Physical Architecture developed by the systems engineers, including mission requirements and human engineering requirements. This task is conducted in parallel with a similar task of the systems engineers where system-level allocations are compared to the selected architecture. This task may not be necessary if all human engineering function allocation recommendations (official) were accepted and followed and if all original assumptions were correct.

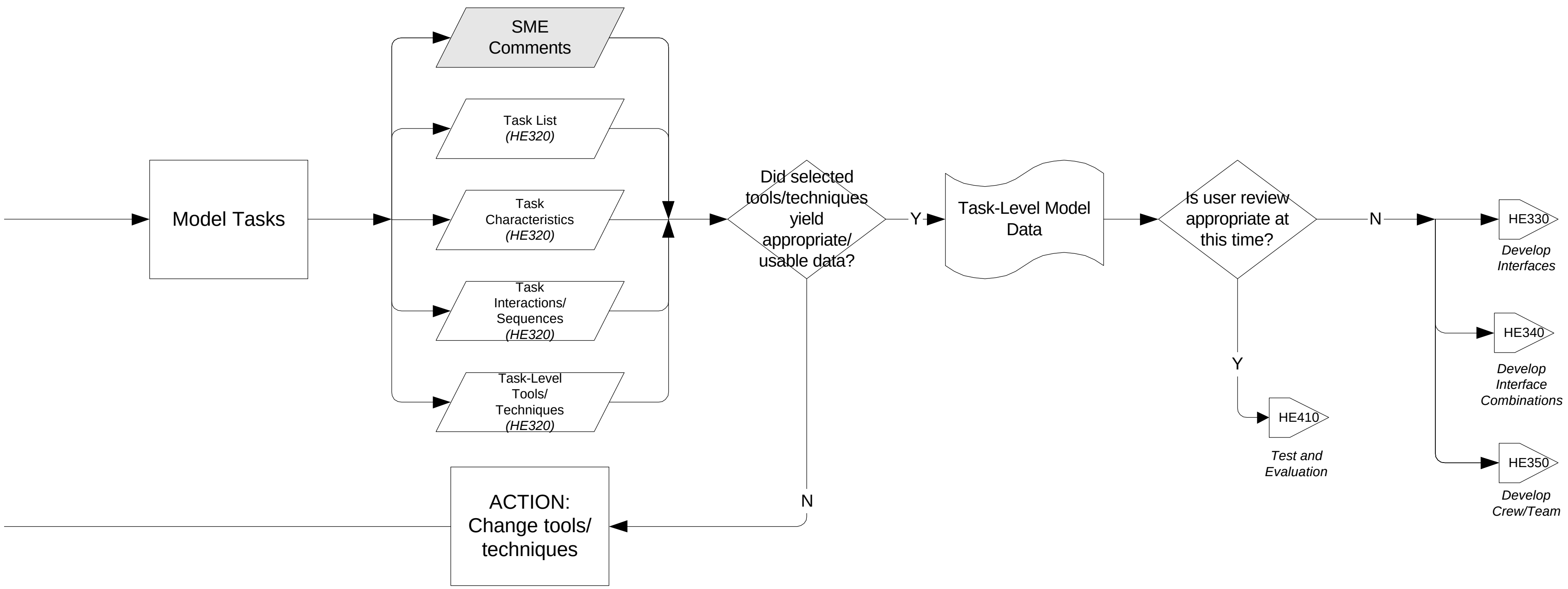
Significant Products:

- Operator and Maintainer Capabilities and Limitations
- Human Engineering Technology Capabilities and Limitations
- Human Engineering Mandatory Function Allocation
  Task feed from Estimate Performance, Workload, and Training Levels (HE360) and Test and Evaluation(HE410) will feed in here from the above decision. This product is submitted to System Engineering Team for review and approval.
- Updated User KSAs
  Updated KSAs may be the same as those in HE110 if changes are not required based on recommendations.
- Human Engineering Function Allocation (official)
  This "official" version of the function allocation is written by the human engineer and given a stamp of approval by the systems engineers. This human engineering allocation is actually a subset of function allocation decisions produced in SE310.
- HE Evaluation of Candidate Physical Architecture

HE 320 – Task Design and Analysis


HE320 - Task Design & Analysis
LAST EDIT DATE: 3/1/00
This includes decomposition of tasks and mission and non-mission tasks (such as HCI or general human tasks) as well as physical and cognitive tasks.
HE310
Function Allocation
HE330
Develop Interfaces
HE340
Develop Interface Combinations
HE350
Develop Crew/Team
HE360
Estimate Performance, Workload, and Training Levels
HE410
Test and Evaluation
Identify Human Tasks
Functional Element Allocation Options (SE310)
Physical Architecture (SE320)
Interface-Specific Tasks (HE330)
Interface Combination-Specific Tasks (HE340)
Crew/Team-Specific Tasks (HE350)
Have all tasks to be carried out by humans been identified?
Y
N
Task List
Identify and Define Individual Task Characteristics
Identify Task Interactions/ Sequences


Concept of Operations
Operational Requirements Document
Task List (HE320)
Task-Level Model Data (HE320)
Task Interactions/ Sequences (HE320)
Have sufficient task characteristics been identified for User Review?
Y
Task Characteristics
N
Concept of Operations
Operational Requirements Document
Task List (HE320)
Task Characteristics (HE320)
Functional Element Allocation Options (SE310)
Have sufficient task interactions/ sequences been identified for User Review?
Y
Task Interactions/ Sequences
N
Is there sufficient information regarding how the tasks will be performed ?
Y
ACTION: Select Task-Level Tools/ Techniques
Task-Level Tools/ Techniques
N
ACTION: Revisit info required and add as needed for clarifying "how" and modeling.



Model Tasks
SME Comments
Task List (HE320)
Task Characteristics (HE320)
Task Interactions/ Sequences (HE320)
Task-Level Tools/ Techniques (HE320)
Did selected tools/techniques yield appropriate/ usable data?
Y
N
ACTION: Change tools/ techniques
Task-Level Model Data
Is user review appropriate at this time?
Y
N
HE410
Test and Evaluation
HE330
Develop Interfaces
HE340
Develop Interface Combinations
HE350
Develop Crew/Team

HE 320 – Task Design and Analysis

Narrative:

Based on the functions allocated to humans and those that will be a combination of software, hardware, and humans, develop the human tasks required to ensure successful completion of each function. Task analysis is a flexible process and may be modified for particular systems. Task development is based on a decision analysis approach. This produces a depiction of the task in terms of the cues to alert the human that a decision/action needs to be taken, the decisions/action to be made, the information required to support the decision, and mechanisms to implement the results of the decision/action. The critical characteristics and interactions are also articulated.

Task analysis within the human engineering process focuses on the identification and description of the tasks to be performed by humans based on the functions allocated. After identifying those tasks, characteristics are defined in terms of the parameters of each, sequences, the effects of performing them, interactions between them, and so on. Information obtained as characteristics can then be used to model the tasks using simulation tools. Tools and techniques must be selected based on the type of information that will be produced and whether or not it will be useful in the analysis.

This analysis will provide a comparison between the performance requirements and the users' capabilities down to the operator/maintainer level. Included in task analysis are the information requirements, evaluations and decisions, task times, operator actions, and environmental conditions. Subject matter experts (SMEs) are used to extract information from the functional analysis as well as their own personal experience for application to the design of the tasks. Task analysis should be conducted for operation in both normal and emergency conditions. In addition, the analysis should range in detail from the gross level (major tasks) to the critical tasks (including those tasks that may not be deviated from in terms of the sequence, duration, timeframe, or possibly unsafe tasks).

<u>Identify Human Tasks</u>

Identify the tasks and decomposition of tasks that are to be carried out by human operators, users, or maintainers. Both mission and non-mission tasks (such as human-computer interaction or general human tasks) that are derived from allocations or previous design decisions are included. Tasks will be identified from the gross level to the critical task level (those that may compromise safety or that have the possibility of increased efficiency and therefore need definition to the subtask level).

Physical and cognitive tasks must be included, as must tasks that change due to dynamic function allocation. Cognitive task analysis is used to describe the knowledge and cognitive processes involved in human performance. Tasks today are more complex and may be performed by an intelligent system that will need the information that is derived from this kind of analysis (decisions, etc.). Decisions required for task completion are articulated and the information requirements for the decisions are documented. Also included here are the tasks that are specifically created by certain interfaces, combinations and/or crew/team configurations (only available at later stages).

Sources:
1. section 2.3.3.3, page 36
4. V2I2 section 4
6. sections 3.2.1.3, 3.2.1.3.1, 3.2.1.3.2
7. sections 1.6.2-1.6.8
9. page 106
10. section 6.1.8
11. pages 148-149

<u>Identify and Define Individual Task Characteristics</u>

Identify the information, actions, location, environmental conditions, physical workspaces, and events (internal and external to the system) that are required for the human tasks to be initiated, continued, or terminated. The characteristics are based on the operational requirements document and any model data and task sequence information available up to this point. Included in the description of the tasks may be information requirements (characteristics, cues, availability, feedback), performance requirements (accuracy, etc), decision requirements, support requirements, safety requirements. The tasks should be described for both normal and emergency conditions (reflecting the scenarios chosen).

Estimate the mean and distribution of the time required to perform the tasks assigned to the humans, including estimations of worst-case durations. Estimate the frequencies or rates of occurrence of the tasks to be performed by the human operators and maintainers. Estimate the priorities of the tasks assigned to humans with respect to the system mission and overall performance and then estimate the priorities that the operators, users, and maintainers will give to their assigned tasks. Estimate the effects of discrepancies in the two types of priorities and ways to resolve the differences or eliminate their effects. Estimate both the accuracy of the human in performing the assigned tasks and the probability of success. Timelines can provide durations of activities plotted along an x-axis for analysis of workload and resource estimation including parallel tasks. A greater level of definition is necessary for critical tasks with respect to cues for task initiation, frequency and tolerances of action, time, and hazards involved.

Sources:
4. V2I2 section 4.1
6. sections 3.2.1.3, 3.2.1.3.1, 3.2.1.3.2
7. section 1.6.2-1.6.8
10. section 6.1.8
11. pages 151-166

<u>Identify Task Interactions/Sequences</u>

Identify the sequence of the tasks and networks of tasks assigned to humans, including tasks that are to be performed simultaneously and coordinate the sequence with the sequence of functions assigned to equipment. Identify interactions between tasks and between tasks and factors external to the system.

Identify how the presence or absence of system inputs and outputs will alter the task flow of the operators, users, and maintainers. This includes the identification of task overlaps and wait times not previously addressed and interaction with tasks or functions allocated to non-human system components. This may include the interactions between similar tasks and the hierarchy of tasks to sub-tasks (serial or parallel arrangements).

Sources:

4. V2I2 section 4.2, 4.3
6. sections 3.2.1.3, 3.2.1.3.1, 3.2.1.3.2
7. section 1.6.9
10. section 6.1.8
11. pages 151-166

<u>Select Task-Level Tools/Techniques</u>

Task-level tools/techniques will help estimate both the accuracy of the human in performing the assigned tasks and the probability of success. Identify the types of errors that may be committed by human operators, users, and maintainers in carrying out their assigned tasks and estimate the effects of errors or failures to complete the tasks on the system, its components, and other functions and tasks. Tasks for fault recovery and human take-over for automation failure and hardware/software take-over for human failure must be included and addressed through the remainder of the design process. The product will be a list or selected tool/technique in modeling the tasks like OSDs, flow process charts, etc.

Sources:

4. V2I2 section 4
11. pages 152-166
36. sections 12.1-12.9

<u>Model Tasks</u>

This task yields the types of data that the tools/techniques selected will provide and the format that they will be in. Using the tools and techniques selected in the previous task unit, data, or information. One example is a sequence of tasks with graphic symbols that are coded with task characteristics, timelines, etc.

This task unit may be thought of as a check of the outputs of the selected tools/techniques and whether or not they will be useful in the development of interfaces and crews/teams. The review may be conducted by SMEs for a more educated view of what is “usable data” or variables of interest, but in the case of unsatisfactory tools and techniques, there must be a return to the selection process. Models will be based on scenarios and functions defined earlier.

Sources:

4. V2I2 section 4
7. section 1.7.2
11. pages 152-166
36. sections 12.1-12.9

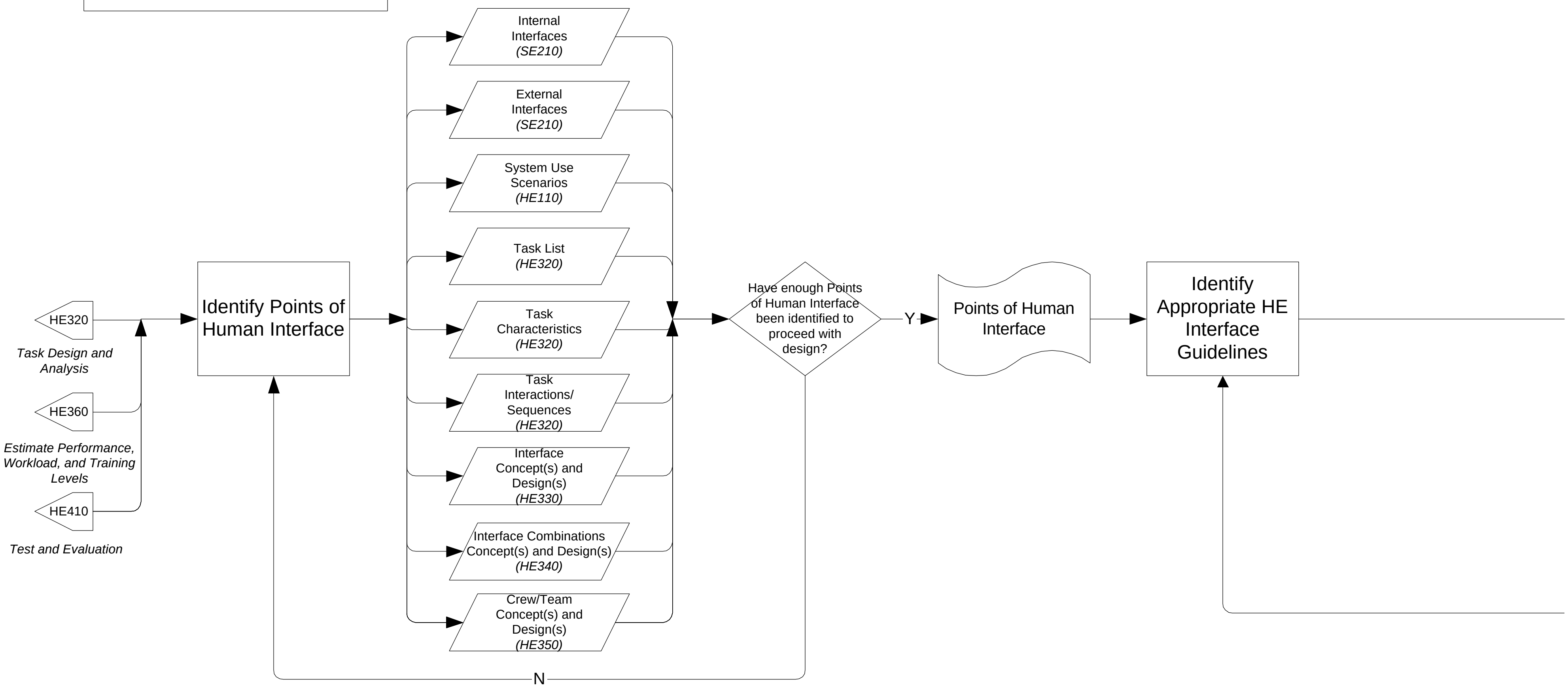
Significant Products:

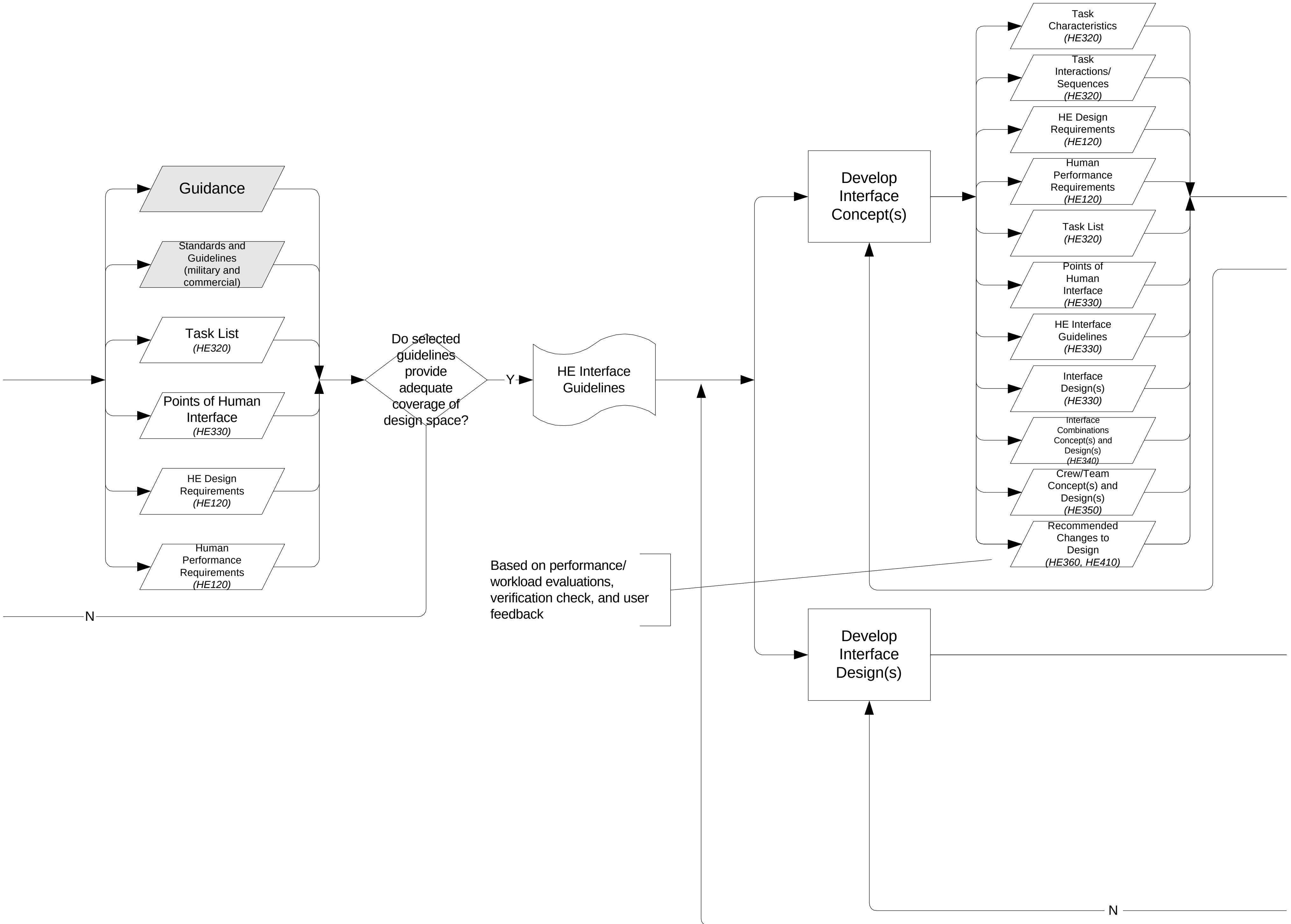
- Task List
- Task Characteristics

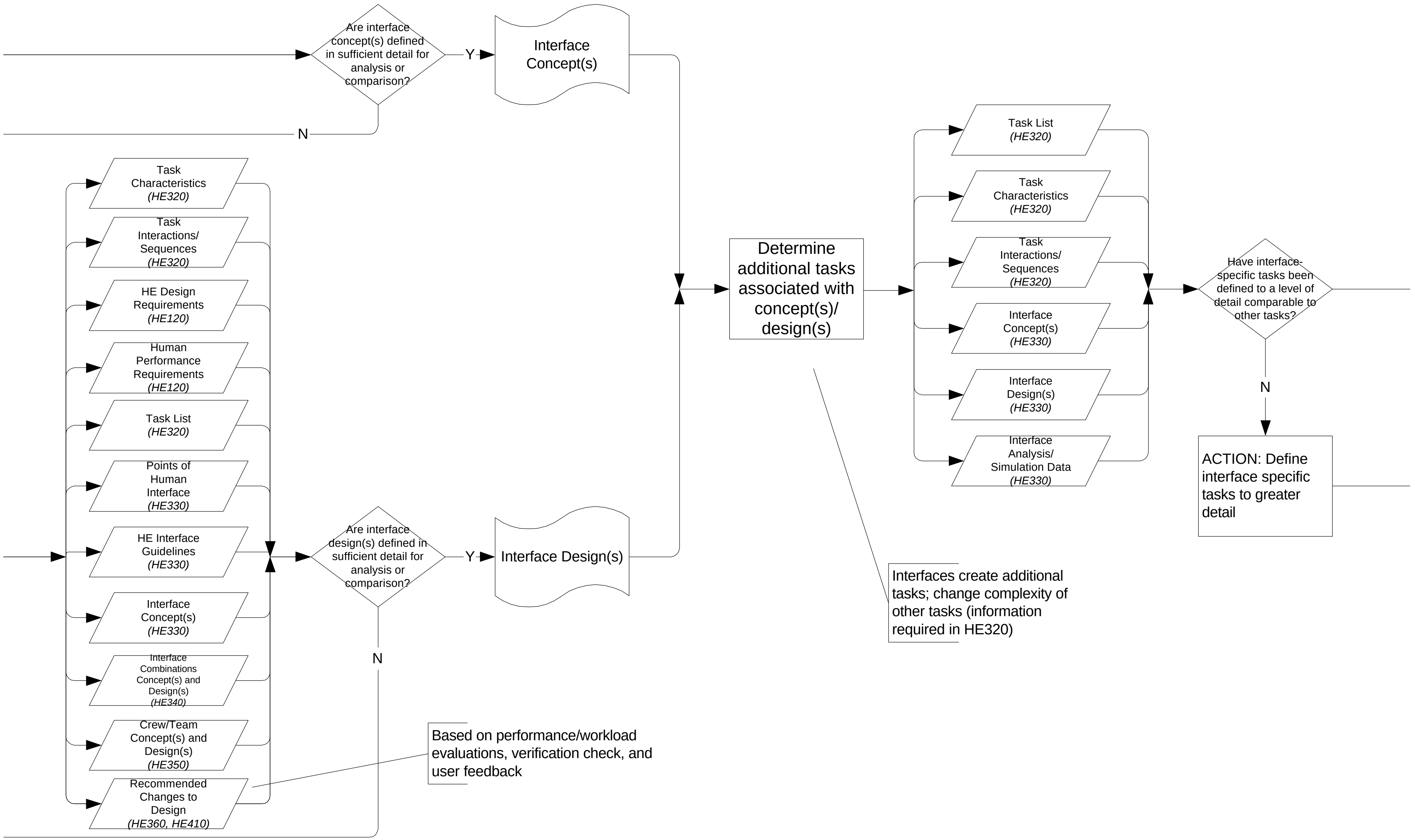
- Task Interactions/Sequences
- Task-Level Tools/Techniques
- Task-Level Model Data

HE 330 – Develop Interfaces

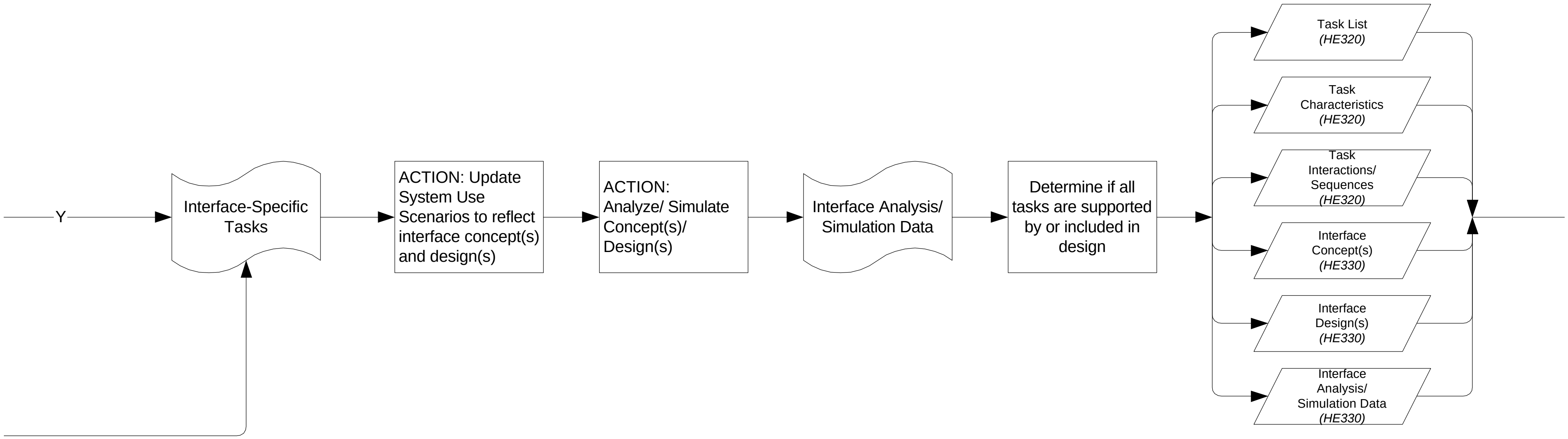
HE330 - Develop Interfaces
LAST EDIT DATE: 3/1/00

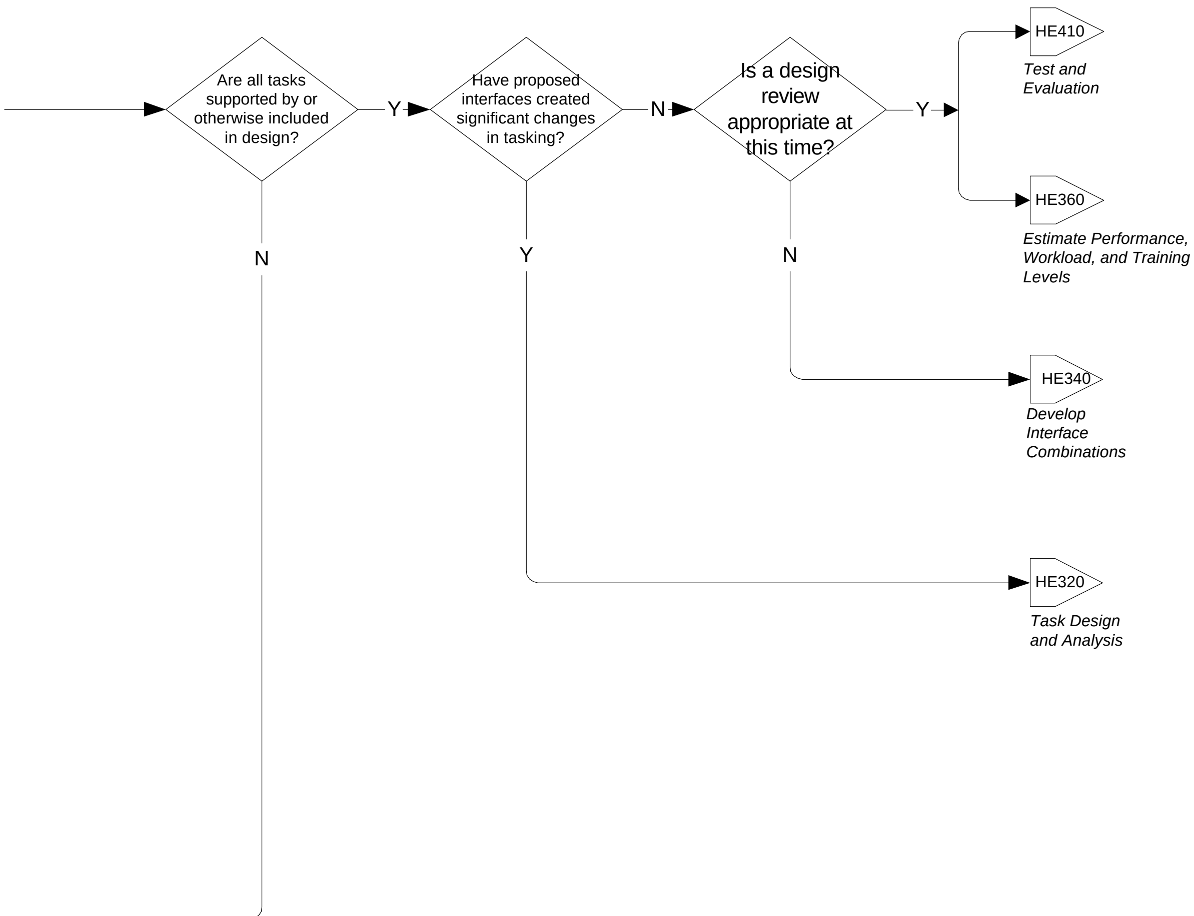



Guidance
Standards and Guidelines (military and commercial)
Task List (HE320)
Points of Human Interface (HE330)
HE Design Requirements (HE120)
Human Performance Requirements (HE120)
N
Do selected guidelines provide adequate coverage of design space?
Y
HE Interface Guidelines
Based on performance/ workload evaluations, verification check, and user feedback
Develop Interface Concept(s)
Develop Interface Design(s)
Task Characteristics (HE320)
Task Interactions/ Sequences (HE320)
HE Design Requirements (HE120)
Human Performance Requirements (HE120)
Task List (HE320)
Points of Human Interface (HE330)
HE Interface Guidelines (HE330)
Interface Design(s) (HE330)
Interface Combinations Concept(s) and Design(s) (HE340)
Crew/Team Concept(s) and Design(s) (HE350)
Recommended Changes to Design (HE360, HE410)
N



Are interface concept(s) defined in sufficient detail for analysis or comparison?
Y
N
Interface Concept(s)
Task Characteristics (HE320)
Task Interactions/ Sequences (HE320)
HE Design Requirements (HE120)
Human Performance Requirements (HE120)
Task List (HE320)
Points of Human Interface (HE330)
HE Interface Guidelines (HE330)
Interface Concept(s) (HE330)
Interface Combinations Concept(s) and Design(s) (HE340)
Crew/Team Concept(s) and Design(s) (HE350)
Recommended Changes to Design (HE360, HE410)
Based on performance/workload evaluations, verification check, and user feedback
Are interface design(s) defined in sufficient detail for analysis or comparison?
Y
N
Interface Design(s)
Determine additional tasks associated with concept(s)/ design(s)
Interfaces create additional tasks; change complexity of other tasks (information required in HE320)
Task List (HE320)
Task Characteristics (HE320)
Task Interactions/ Sequences (HE320)
Interface Concept(s) (HE330)
Interface Design(s) (HE330)
Interface Analysis/ Simulation Data (HE330)
Have interface-specific tasks been defined to a level of detail comparable to other tasks?
N
ACTION: Define interface specific tasks to greater detail


Y
Interface-Specific Tasks
ACTION: Update System Use Scenarios to reflect interface concept(s) and design(s)
ACTION: Analyze/ Simulate Concept(s)/ Design(s)
Interface Analysis/ Simulation Data
Determine if all tasks are supported by or included in design
Task List
(HE320)
Task Characteristics
(HE320)
Task Interactions/ Sequences
(HE320)
Interface Concept(s)
(HE330)
Interface Design(s)
(HE330)
Interface Analysis/ Simulation Data
(HE330)


Are all tasks supported by or otherwise included in design?
Y
N
Have proposed interfaces created significant changes in tasking?
N
Y
Is a design review appropriate at this time?
Y
N
HE410
Test and Evaluation
HE360
Estimate Performance, Workload, and Training Levels
HE340
Develop Interface Combinations
HE320
Task Design and Analysis

HE 330 – Develop Interfaces

Narrative:

Concepts and designs for the interfaces between humans and other systems components (i.e., software, hardware, or other humans) need to be identified. Three levels of interfaces should be described starting with individual interfaces that represent a particular interaction, then building into combinations of interfaces at the individual operator level. These individuals are then assembled into crews or teams employing multiple-operator interface concepts and designs.

The individual interfaces considered first are those between a single operator and another system component, and are based on the task analysis as well as performance and design requirements. The interaction of humans with other system components will also be based on the functional architecture, allocation decisions, and human engineering inputs. Some elements of both internal and external interfaces will have already been defined as interfaces between functions within the functional architecture. The points of human interface and interface guidelines are established to direct the development of the interface concepts and designs. Once these concepts and designs are developed, additional tasks resulting from the design are outlined and the System Use Scenarios are updated as necessary. The concepts and designs are then analyzed and simulated, and verification takes place to ensure that all operator tasks are supported by the design.

<u>Identify Points of Human Interface</u>

Before interface concepts and designs can be established, it is important to identify and understand where and how within the system interactions between users and equipment (hardware or software) or another human occur. These points of human interface are the places in the allocated functional architecture where data, information, objects, etc. are transitioned between humans or humans and equipment. Information of interest includes the data that is to be transmitted, the nodes or elements between which data is transmitted, when the data is transmitted, and other interface-specific constraints, such as special conditions based on times and events. These variables should be defined to a sufficient level of detail for the current status of the design. Understanding the points of human interface is crucial in the development of the interface concepts and designs because the interfaces must first be identified before they can be developed.

Sources:

5. sections 6.1.7, 6.5.7
9. pages 48-49

<u>Identify Appropriate HE Interface Guidelines</u>

The next important step in interface development is to research appropriate human engineering (HE) interface guidelines to ensure that the utility of the interface is maximized and that any guidelines included as design requirements are fulfilled. Existing guidelines applicable to the information or material passed between humans or between humans and equipment should be identified. These guidelines will also assist in keeping the design in accordance with constraints, heuristics, and prior human engineering research. Guidelines may include, but are not limited to, short term and working memory limitations, display and control modalities, and physical or strength limitations. These guidelines include those defined in, derived from, or implied by human and job/task requirements. The most important criterion in selecting guidelines is to identify those that will help in building and selecting designs.

Sources:

5. section 6.1.3
9. pages 58-64
12. sections 2.2, 2.3
21. sections 4-5

Develop Interface Concepts

The concepts underlying the individual interfaces between system elements - such as humans, hardware, and software - are a crucial component of the overall interface development. The potential concepts are developed and then iteratively refined in parallel with the interface designs under development. Interface concepts are created based on the requirements for interaction between humans and other system components that are specified in the human engineering requirements development phase. The interface concepts and designs must satisfy all human engineering requirements such as the transfer of information, timing, and physical location. Due to the potentially significant and varied amount of information to be transferred, the process of developing interface concepts and designs is highly creative. The concepts are less detailed and concrete than the designs but are closely tied with their development, as they feed off of each other.

Sources:

1. section 2.3.3.3, page 37
4. V2I2 section 6
7. section 1.4.7
9. pages 49-50

Develop Interface Designs

The interface designs are initially based on the selected interface concepts, and then both are refined in an iterative fashion. The concepts and designs are highly dependent on one another and must form a cohesive whole. The interface at this point is defined in general terms and should include factors such as information representation (graphics as opposed to text), modality specification (input and output modalities), etc. It is also useful to verify that the system architecture and modality choices are driven by users' needs, not the architecture of particular software programs. However, in some cases interface design may be highly constrained due to other design decisions, such as specific pieces or types of hardware and software that are to be used.

Sources:

1. section 2.3.3.3, page 37
4. V2I2 section 6
5. section 6.5.2
9. pages 49-50

10. section 6.1.9

Determine additional tasks associated with designs/concepts

Once the interface designs and concepts are developed, they should be assessed to determine the extent to which the interface creates additional tasks and/or changes the complexity of existing tasks. It is necessary to determine how the selected interface affects the task performance of the human. A description of the non-mission tasks (such as human-computer interaction tasks) that the interface has added to the original task set assigned to the human is also useful, as well as an assessment of the compliance of these tasks with both human and job/task requirements. The interface-specific tasks identified should feed back into the *Task Design and Analysis* process and become an information requirement for further refinements of the task list.

Sources:

1. section 2.3.3.3, page 36
4. V2I2 section 4
6. sections 3.2.1.3, 3.2.1.3.1, 3.2.1.3.2
7. sections 1.6.2-1.6.9
10. section 6.1.8
11. pages 148-149

Update System Use Scenarios to reflect interface concepts and designs

By this point in the process the System Use Scenarios developed in the *Mission Analysis* may be outdated, perhaps even significantly, as design decisions have been made. Thus, it is useful to take a step back and reconsider the System Use Scenarios in light of the interface concept and design alternatives. If required, the System Use Scenarios should be updated to concur with the current designs. The System Use Scenarios are important inputs in later processes such as workload and performance estimation, requirements verification, and user review. Therefore, it is crucial that they reflect the interface concepts and designs accurately.

Sources:

4. V2I2 section 1.1
5. section 6.1.4
7. sections 1.1.7, 1.2.2

Analyze/Simulate Concepts/Designs

The next step is to simulate and test the individual human interface designs. Simulating the concepts and designs is often done utilizing models and/or prototypes. Simulations may be static or dynamic, part or whole task, open or closed loop, and may include a human operator, be conducted without an operator, or with an operator model. Design alternatives are analyzed to determine which potential solution is the best match with the functional, performance, and interface requirements, and to ensure that they satisfy the design constraints and workload limitations. These techniques are useful in reducing the possible risks with integrating technologies, especially new and emerging technologies. In addition, models and prototypes are an appropriate way to verify that the design concurs with the functional architecture. Finally, the design that will be selected should be one that maximizes the contribution to the overall system effectiveness.

Sources:

1. section 2.3.4
5. section 6.5.2, 6.5.11
6. section 3.2.2.1
9. pages 50-51, 123-130
10. sections 6.1.13, 6.1.14, 6.1.15

<u>Determine if all tasks are supported by or included in design</u>

Once designs with good potential have been identified, it is beneficial to consider the task list and verify that all tasks were addressed in the design process. A check should confirm that any task that needs to be either supported by or directly included in the interface design has been addressed. If during this audit it is found that tasks that should be supported by the design have not be taken into account, this is an indication that rework or further refinement of the design is required.

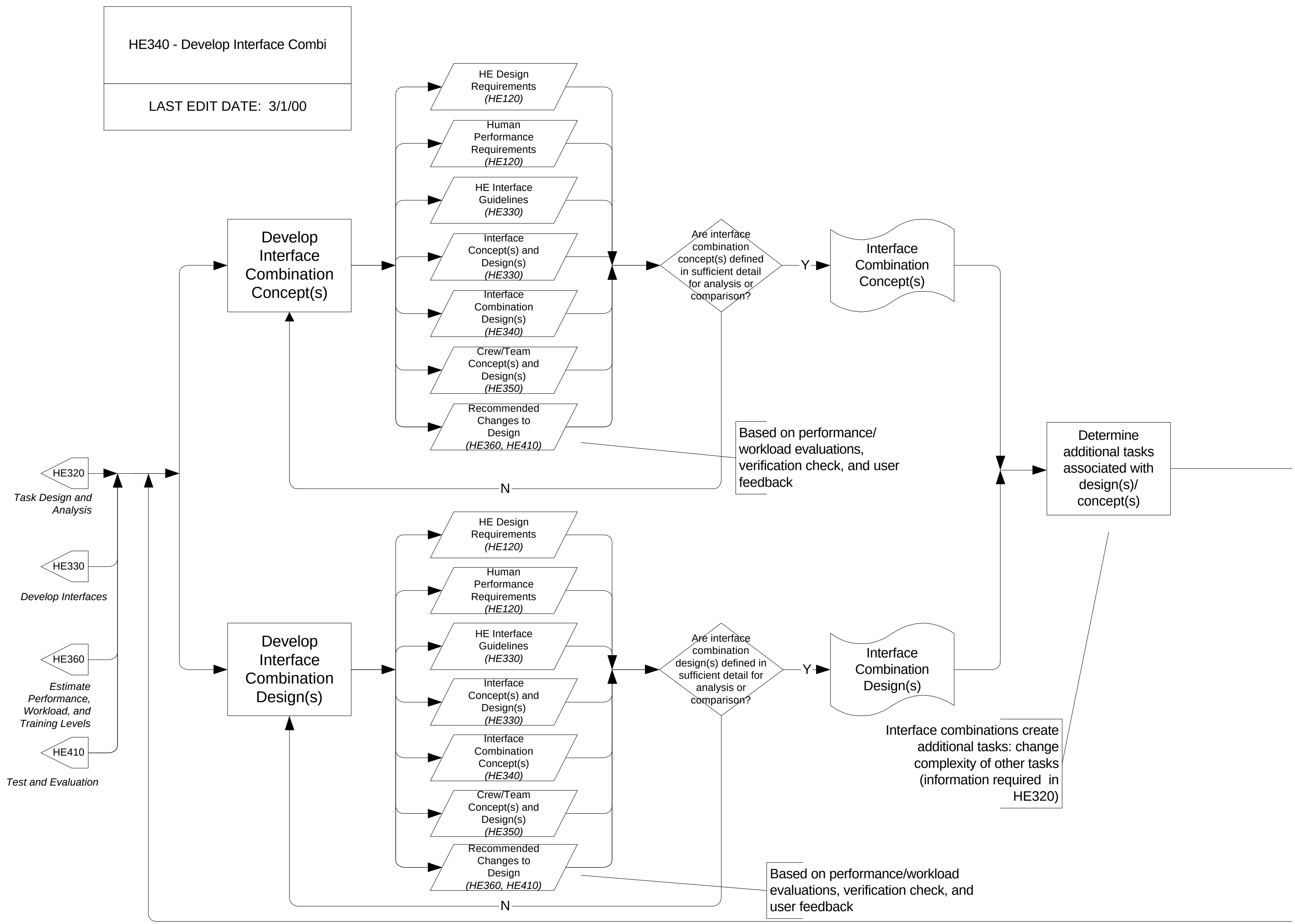
Sources:

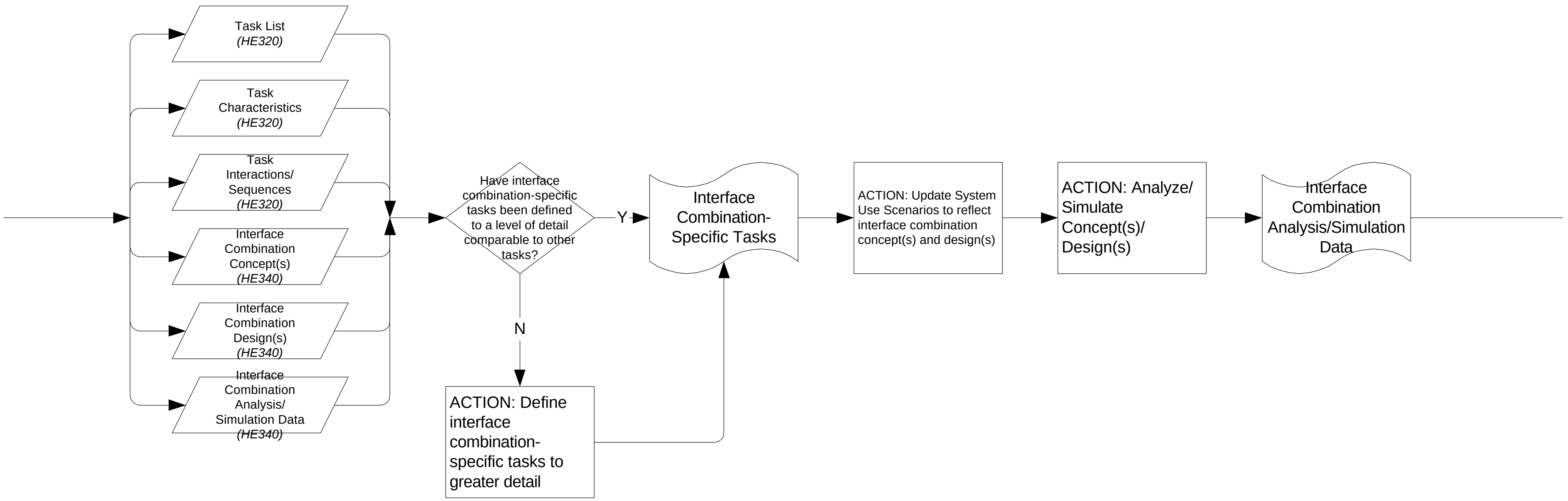
5. section 6.6.2.1

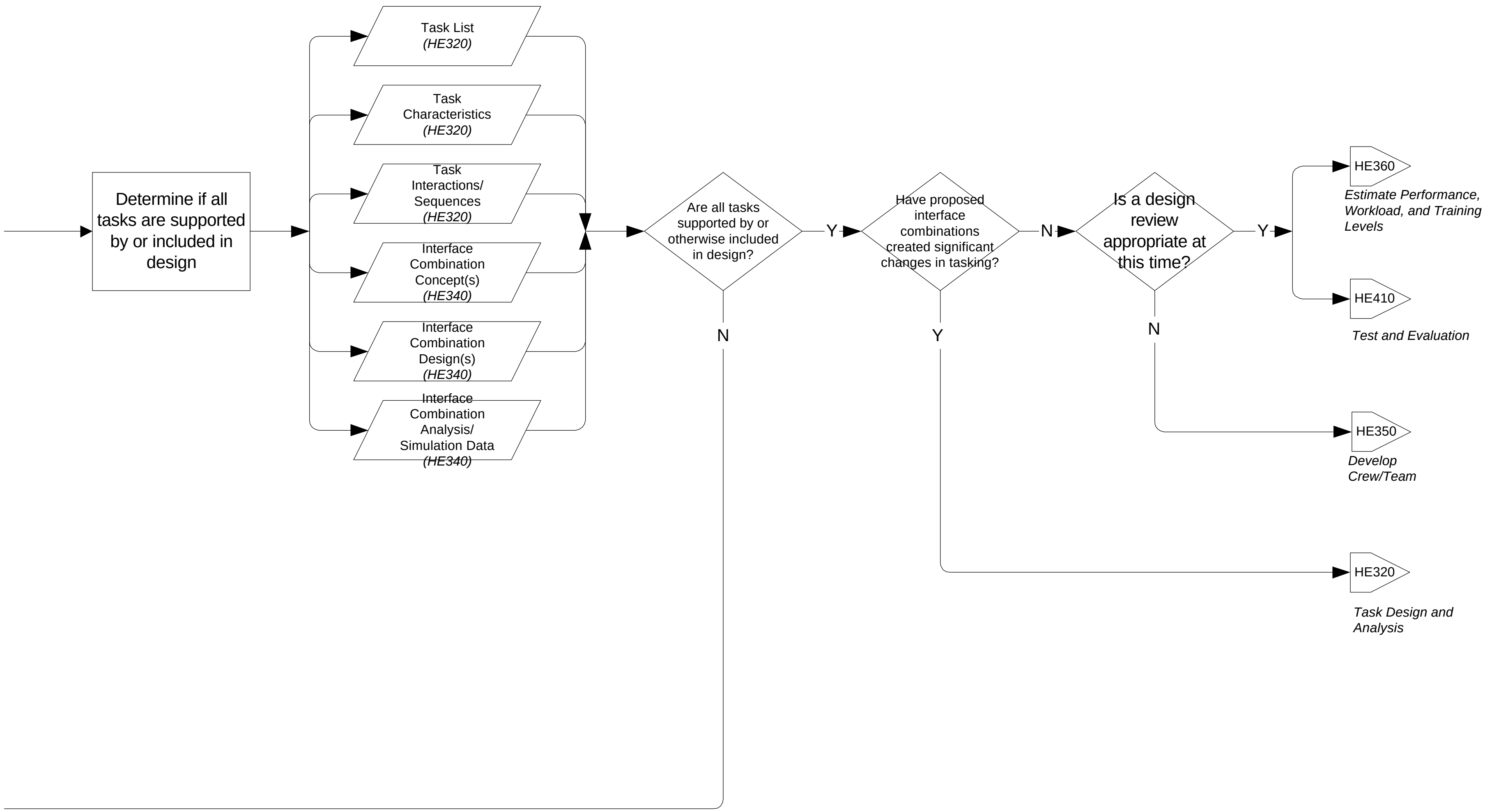
Significant Products:

- Points of Human Interface
- Interface Concept(s) or Design(s)
- Interface-Specific Tasks
- Interface Analysis/Simulation Data

HE 340 – Develop Interface Combinations


HE340 - Develop Interface Combi
LAST EDIT DATE: 3/1/00
HE320
Task Design and Analysis
HE330
Develop Interfaces
HE360
Estimate Performance, Workload, and Training Levels
HE410
Test and Evaluation
Develop Interface Combination Concept(s)
HE Design Requirements (HE120)
Human Performance Requirements (HE120)
HE Interface Guidelines (HE330)
Interface Concept(s) and Design(s) (HE330)
Interface Combination Design(s) (HE340)
Crew/Team Concept(s) and Design(s) (HE350)
Recommended Changes to Design (HE360, HE410)
Are interface combination concept(s) defined in sufficient detail for analysis or comparison?
Y
N
Interface Combination Concept(s)
Based on performance/ workload evaluations, verification check, and user feedback
Develop Interface Combination Design(s)
HE Design Requirements (HE120)
Human Performance Requirements (HE120)
HE Interface Guidelines (HE330)
Interface Concept(s) and Design(s) (HE330)
Interface Combination Concept(s) (HE340)
Crew/Team Concept(s) and Design(s) (HE350)
Recommended Changes to Design (HE360, HE410)
Are interface combination design(s) defined in sufficient detail for analysis or comparison?
Y
N
Interface Combination Design(s)
Based on performance/workload evaluations, verification check, and user feedback
Determine additional tasks associated with design(s)/ concept(s)
Interface combinations create additional tasks: change complexity of other tasks (information required in HE320)


Task List
(HE320)
Task
Characteristics
(HE320)
Task
Interactions/
Sequences
(HE320)
Interface
Combination
Concept(s)
(HE340)
Interface
Combination
Design(s)
(HE340)
Interface
Combination
Analysis/
Simulation Data
(HE340)
Have interface combination-specific tasks been defined to a level of detail comparable to other tasks?
Y
N
ACTION: Define interface combination-specific tasks to greater detail
Interface Combination-Specific Tasks
ACTION: Update System Use Scenarios to reflect interface combination concept(s) and design(s)
ACTION: Analyze/ Simulate Concept(s)/ Design(s)
Interface Combination Analysis/Simulation Data


Determine if all tasks are supported by or included in design
Task List
(HE320)
Task Characteristics
(HE320)
Task Interactions/ Sequences
(HE320)
Interface Combination Concept(s)
(HE340)
Interface Combination Design(s)
(HE340)
Interface Combination Analysis/ Simulation Data
(HE340)
Are all tasks supported by or otherwise included in design?
Y
N
Have proposed interface combinations created significant changes in tasking?
N
Y
Is a design review appropriate at this time?
Y
N
HE360
Estimate Performance, Workload, and Training Levels
HE410
Test and Evaluation
HE350
Develop Crew/Team
HE320
Task Design and Analysis

HE 340 – Develop Interface Combinations

Narrative:

After the development of the concepts and designs of the individual interfaces (between an operator and another system component - either hardware, software, or a human) has been completed, the interface combinations should be considered. In general, operators will interact with a number of system components in the course of completing their jobs. The interfaces may individually be well designed, but in combination can create unique stresses or beneficial opportunities. For example, if two screens are have conflicting coding schemes, they might be easy to work individually but confuse the operator who must work with both. Interfaces must be considered in combination in order to minimize conflicts between different interfaces encountered by a single operator. In addition, all of the interfaces that individuals are utilizing must be considered as a whole in order to fully understand the task and workload demands placed on the operators, and to identify additional tasking that is created by the interface combinations. It is also helpful to update the System Use Scenarios and analyze the interface combination concepts and designs, as with the previous process with individual interfaces. The final step is to verify that all tasks are considered in the concepts and designs.

<u>Develop Interface Combination Concepts</u>

Much like the individual interface concepts, potential interface combination concepts are developed and iteratively refined in parallel with the interface combination designs. When concepts are developed, their distinguishing features should be identified and taken into account to determine the alternatives that might provide the maximum benefit for overall system effectiveness. Based on these features, the concepts with the greatest potential for the human interface combinations or workstations and work environments should be identified. It is also crucial that interference between tasks and interface combinations should be identified and resolved.

Sources:

1. section 2.3.3.3, page 38
4. V2I2 section 6.1
6. section 3.2.2.3
7. section 1.4.7

<u>Develop Interface Combination Designs</u>

The interface combination designs are initially based on the interface combination concepts, and then both are refined in an iterative fashion. As was the case with individual interfaces, interface combination concepts and designs are highly dependent on one another and must form a cohesive whole. The designs need to be considered in combination in order to reduce possible incompatibilities between interfaces. The goal is to identify the best from among the alternate human interface combinations or workstations and work environments developed from the concepts. Designs should be chosen based on their ability to promote compatibility and eliminate confusion and discrepancy between interfaces of individual components.

Sources:
1. section 2.3.3.3, page 38
4. V2I2 section 6.1
5. section 6.5.2
6. section 3.2.2.3

<u>Determine additional tasks associated with designs/concepts</u>

Once the interface combination designs and concepts are developed, they should be assessed to determine the extent to which the interface combinations create additional tasks and/or change the complexity of existing tasks. It is necessary to determine how the selected interface combinations affect the task performance of the human. A description of any additional non-mission tasks (such as human-computer interaction tasks) that the combination of the interfaces has added to the revised task set assigned to the human is also useful, as well as an assessment of the compliance of these tasks with both human and job/task requirements. The interface combination-specific tasks identified should feed back into the *Task Design and Analysis* process and become an information requirement for further refinements of the task list.

Sources:
1. section 2.3.3.3, page 36
4. V2I2 section 4
6. sections 3.2.1.3, 3.2.1.3.1, 3.2.1.3.2
7. sections 1.6.2-1.6.9
10. section 6.1.8
11. pages 148-149

<u>Update System Use Scenarios to reflect interface combination concepts/designs.</u>

As the interface combination potential concepts and designs are developed and as iterations to the overall design continue to be made, the System Use Scenarios can easily become out of date. The System Use Scenarios are important inputs in later processes such as workload and performance estimation, requirements verification, and user review. Therefore, it is crucial that they reflect the interface combination concepts and designs accurately. At this point, the System Use Scenarios should be re-evaluated and updated as necessary.

Sources:
4. V2I2 section 1.1
5. section 6.1.4
7. sections 1.1.7, 1.2.2

<u>Analyze/Simulate Interface Combinations</u>

The next step is to simulate and test the interface combinations or workstation and work environment designs. Simulating the concepts and designs is often done utilizing models and/or prototypes. Simulations may be static or dynamic, part or whole task, open or closed loop, and may include a human operator, be conducted without an operator, or with an operator model. Design alternatives are analyzed to determine which potential solution is the best match with the functional, performance, and interface requirements, and to ensure that they satisfy the design constraints and workload limitations. These techniques are useful in reducing the possible risks with integrating technologies, especially new and emerging technologies. In addition, models and prototypes are an appropriate way to verify that the design concurs with the functional architecture. Finally, the design that will be selected should be one that maximizes the contribution to the overall system effectiveness.

Sources:

1. section 2.3.4
5. section 6.5.11
6. section 3.2.2.1
9. pages 50-51, 123-130
10. sections 6.1.13, 6.1.14, 6.1.15

<u>Determine if all tasks are supported by or included in design</u>

Once designs with good potential have been identified, it is beneficial to consider the task list and verify that all tasks were addressed in the design process. A check should confirm that any task that needs to be either supported by or directly included in the interface design has been addressed If during this audit it is found that tasks that should be supported by the design have not be taken into account, this is an indication that rework or further refinement of the design is required.

Sources:

5. section 6.6.2.1

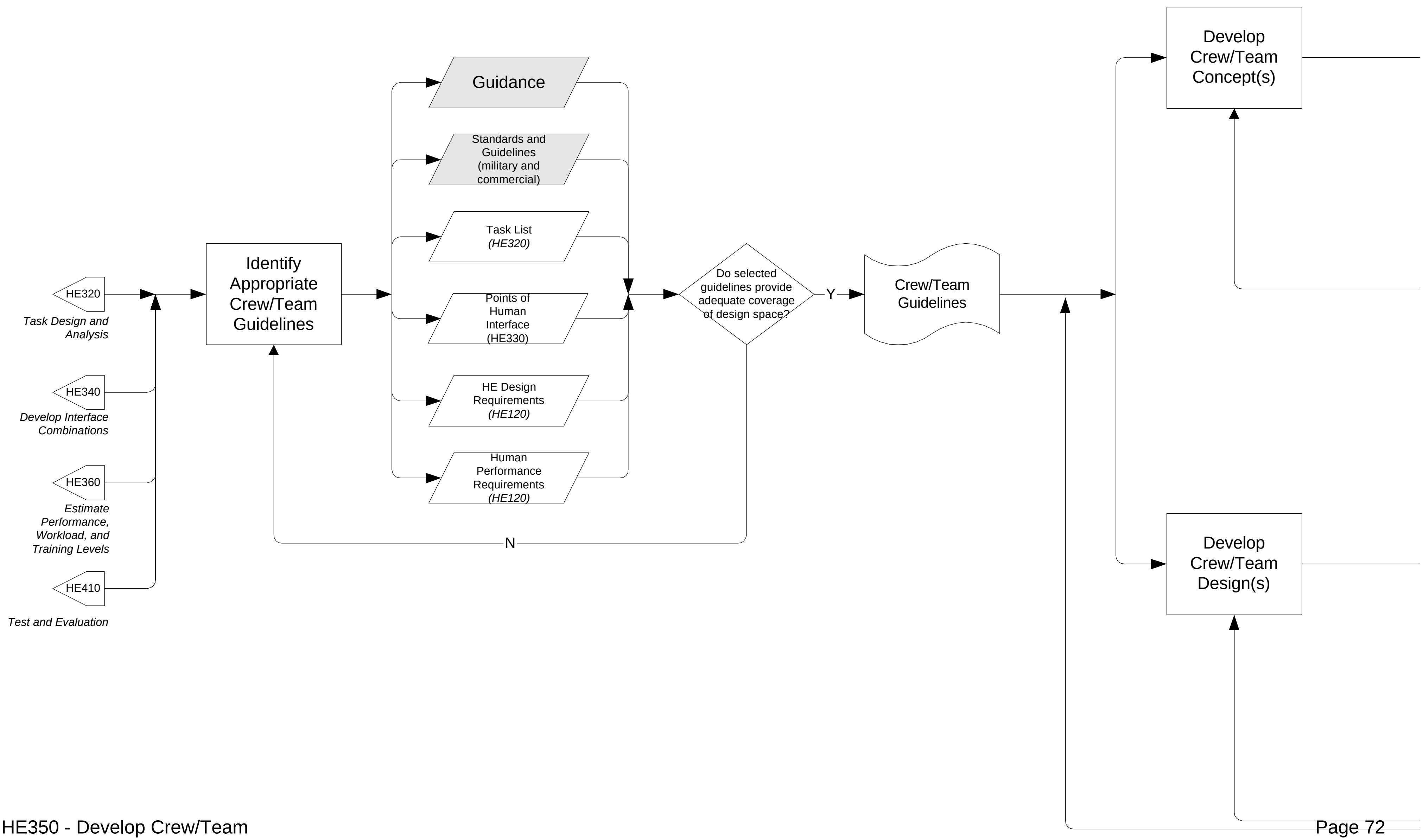
Significant Products:

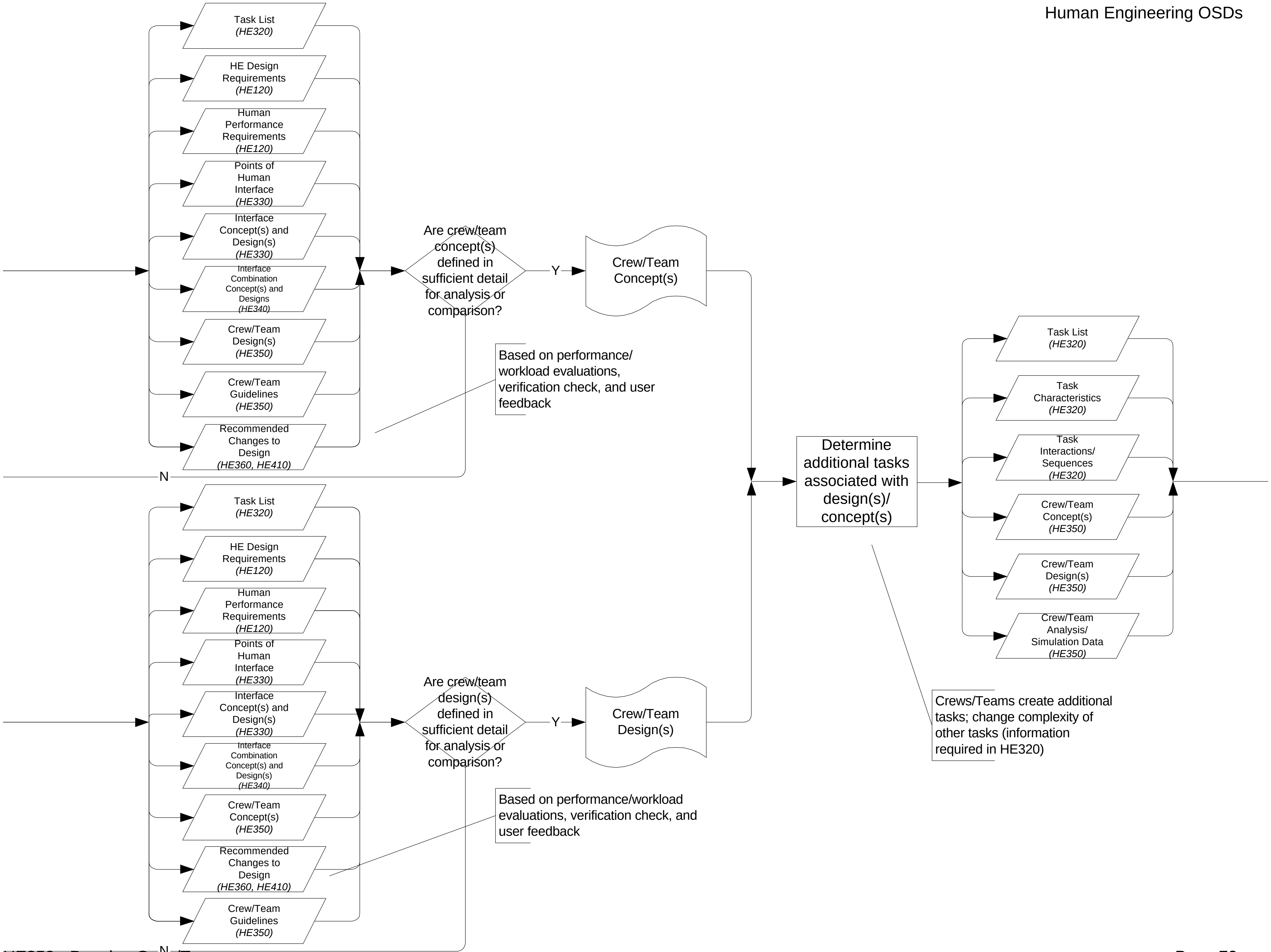
- Interface Combination Concept(s) or Design(s)
- Interface Combination-Specific Tasks
- Interface Combination Analysis/Simulation Data

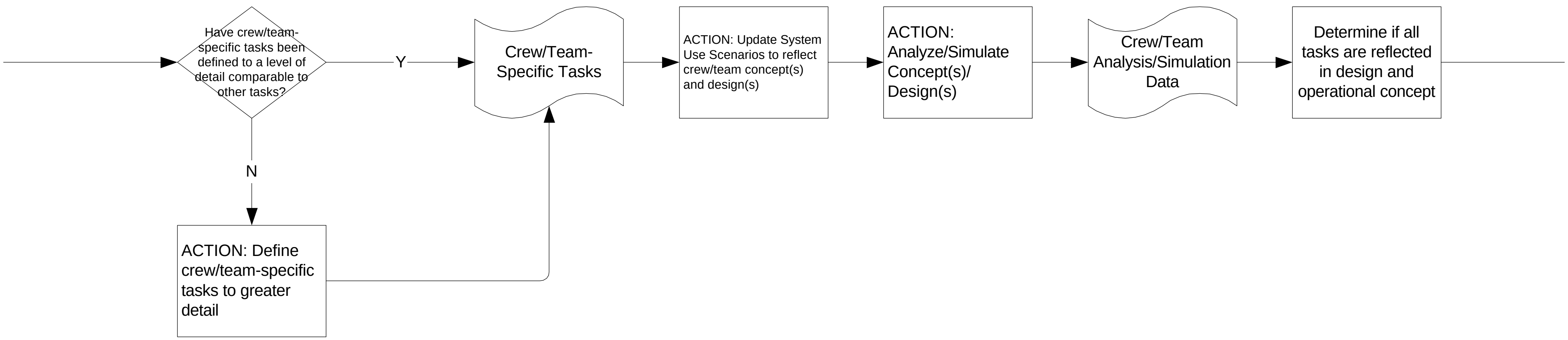
HE 350 – Develop Crew/Team

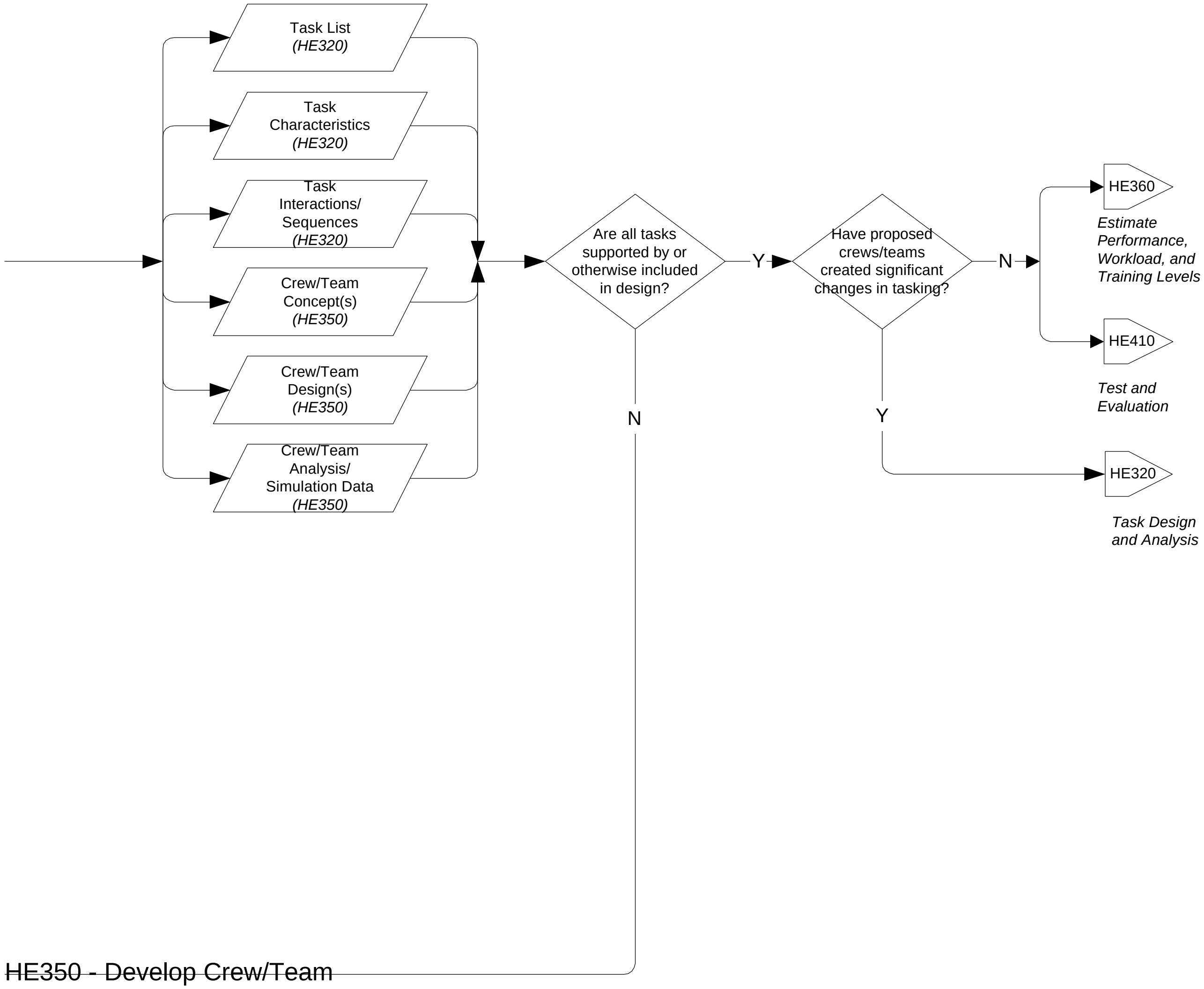
HE350 - Develop Crew/Team

LAST EDIT DATE: 3/1/00




Task List
(HE320)
HE Design Requirements
(HE120)
Human Performance Requirements
(HE120)
Points of Human Interface
(HE330)
Interface Concept(s) and Design(s)
(HE330)
Interface Combination Concept(s) and Designs
(HE340)
Crew/Team Design(s)
(HE350)
Crew/Team Guidelines
(HE350)
Recommended Changes to Design
(HE360, HE410)
Are crew/team concept(s) defined in sufficient detail for analysis or comparison?
Y
N
Crew/Team Concept(s)
Based on performance/ workload evaluations, verification check, and user feedback
Task List
(HE320)
HE Design Requirements
(HE120)
Human Performance Requirements
(HE120)
Points of Human Interface
(HE330)
Interface Concept(s) and Design(s)
(HE330)
Interface Combination Concept(s) and Design(s)
(HE340)
Crew/Team Concept(s)
(HE350)
Recommended Changes to Design
(HE360, HE410)
Crew/Team Guidelines
(HE350)
Are crew/team design(s) defined in sufficient detail for analysis or comparison?
Y
N
Crew/Team Design(s)
Based on performance/workload evaluations, verification check, and user feedback
Determine additional tasks associated with design(s)/ concept(s)
Crews/Teams create additional tasks; change complexity of other tasks (information required in HE320)
Task List
(HE320)
Task Characteristics
(HE320)
Task Interactions/ Sequences
(HE320)
Crew/Team Concept(s)
(HE350)
Crew/Team Design(s)
(HE350)
Crew/Team Analysis/ Simulation Data
(HE350)


Have crew/team-specific tasks been defined to a level of detail comparable to other tasks?
Y
N
Crew/Team-Specific Tasks
ACTION: Update System Use Scenarios to reflect crew/team concept(s) and design(s)
ACTION: Analyze/Simulate Concept(s)/ Design(s)
Crew/Team Analysis/Simulation Data
Determine if all tasks are reflected in design and operational concept
ACTION: Define crew/team-specific tasks to greater detail



Task List
(HE320)
Task
Characteristics
(HE320)
Task
Interactions/
Sequences
(HE320)
Crew/Team
Concept(s)
(HE350)
Crew/Team
Design(s)
(HE350)
Crew/Team
Analysis/
Simulation Data
(HE350)
Are all tasks supported by or otherwise included in design?
Y
N
Have proposed crews/teams created significant changes in tasking?
N
Y
HE360
Estimate Performance, Workload, and Training Levels
HE410
Test and Evaluation
HE320
Task Design and Analysis

HE 350 – Develop Crew/Team

Narrative:

After the development of the concepts and designs of the individual interfaces (between an operator and another system component - either hardware, software, or a human) and the combinations of these individual interfaces have been evaluated, it is crucial to consider the combinations of the individual operators at the crew/team level. In some situations, crew or team designs may be addressed before the interfaces of individual operators are designed, but this should not be done without some estimation of those interaction requirements. Operators will interact not only with a number of system equipment components in the course of completing their jobs, but also a number of other people. Careful planning of team concepts and designs is imperative to ensure that the team works together on both individual and joint tasks efficiently and effectively. As with the previous interface design levels, an operator's interaction with multiple interfaces and other operators must be considered as a whole in order to fully understand the task and workload demands placed on the operators, and to identify additional tasking that is created by the team environment. It is also helpful to perform a final update of the System Use Scenarios and analyze the crew/team concepts and designs. Finally, verification should be conducted to ensure that all tasks are considered in the team concepts and designs.

<u>Identify Appropriate Crew/Team Guidelines</u>

The first step in crew/team development is to research appropriate human engineering (HE) crew/team guidelines to ensure that the utility of the team environment is maximized. A general set of guidelines for team design does not seem to be currently available; however, this is an area of ongoing research. In addition, organization-specific guidelines may exist and should not be overlooked. The crew/team guidelines to be identified should also include those defined in, derived from, or implied by human and job/task requirements. The most important criterion in selecting guidelines is to identify those that will help in building and selecting designs.

Sources:

5. section 6.1.3
9. pages 58-64
37. pages 370-371

<u>Develop Crew/Team Concepts</u>

As with the previous interface concepts, potential crew/team concepts are developed and iteratively refined in parallel with the crew/team designs. When concepts are developed, their distinguishing features should be identified and taken into account to determine the alternatives that might provide the maximum benefit for overall system effectiveness. Based on these features, the concepts with the greatest potential for aiding team interaction and the work of individual team members should be identified. It is also crucial that any interference between tasks and individuals within the team or team inputs and outputs should be considered and resolved.

Team characteristics that might be worth considering are size, homogeneity/heterogeneity, and job flexibility. Additional variables that affect team morale include self-management, participation, task variety, task significance, and task differentiation. Finally, factors that have been shown to aid in effective team processes are potency (or “team spirit”, commit to the work of the group), social support, workload sharing, communication, and cooperation.

Sources:

4. V2I2 section 6
6. section 3.2.2.3
7. section 1.4.7
13. pages 298-302

<u>Develop Crew/Team Designs</u>

The crew/team designs are initially based on the crew/team concepts, and then both are refined in an iterative fashion. As was the case with the previous interaction design levels, crew/team concepts and designs are highly dependent on one another and must form a cohesive whole. The goal is to identify the best candidates from among the alternate team designs developed from the concepts. Team designs will be based on the allocation of tasks and other responsibilities to different operators or team members, and will be influenced by such factors as individual workload and performance levels, team design principles, and overall performance requirements. There are also formal methods that can be applied in an effort to optimize team design. For example, candidate team members can be asked to complete questionnaires that are designed to assess their team skills or prerequisite KSAs, or team design processes based on algorithms, heuristics, and subject matter expert knowledge may be utilized.

Sources:

4. V2I2 section 6
6. section 3.2.2.3
13. pages 298-302
14. sections 14.3-14.4

<u>Determine additional tasks associated with designs/concepts</u>

Once the crew/team designs and concepts are developed, they should be assessed to determine the extent to which the team design creates additional tasks and/or changes the complexity of existing tasks. It is necessary to determine how the selected team design affects the task performance of the human. A description of any additional non-mission tasks that the team design has added to the revised task set assigned to the human is also useful, as well as an assessment of the compliance of these tasks with both human and job/task requirements. The crew/team-specific tasks identified should feed back into the *Task Design and Analysis* process and become an information requirement for further refinements of the task list.

Sources:

1. section 2.3.3.3, page 36
4. V2I2 section 4
6. sections 3.2.1.3, 3.2.1.3.1, 3.2.1.3.2
7. sections 1.6.2-1.6.9
10. section 6.1.8
11. pages 148-149

Update System Use Scenarios to reflect Crew/Team concepts and designs

As the crew/team potential concepts and designs are developed and as final iterations to the overall design continue to be made, the System Use Scenarios can easily become out of date. The System Use Scenarios are important inputs in later processes such as workload and performance estimation, requirements verification, and user review. Therefore, it is crucial that they reflect the crew/team concepts and designs accurately. At this point, the System Use Scenarios should be re-evaluated and updated as necessary.

Sources:

4. V2I2 section 1.1
5. section 6.1.4
7. sections 1.1.7, 1.2.2

Analyze/Simulate Crew/Team Concepts and Designs

The next step is to simulate and test the team concepts and designs. Simulating the concepts and designs is often done utilizing models and/or prototypes. Simulations may be static or dynamic, part or whole task, open or closed loop, and may include a human operator, be conducted without an operator, or with an operator model.

Design alternatives are analyzed to determine which potential solution is the best match with the functional, performance, and interface requirements, and to ensure that they satisfy the design constraints and workload limitations. In addition, models and prototypes are an appropriate way to verify that the design concurs with the functional architecture. Finally, the design candidates should be the ones that maximize the contribution to the overall system effectiveness.

Sources:

1. section 2.3.4
5. section 6.5.11
6. section 3.2.2.1
10. sections 6.1.13, 6.1.14, 6.1.15
14. section 14.5

Determine if all tasks are supported by or included in design/operational concept

Once designs with good potential have been identified, it is beneficial to consider the task list and verify that all tasks were addressed in the design. A check should confirm that any task that needs to be either supported by or directly included in the interface design has been addressed. If during this audit it is found that tasks that should be supported by the design have not been taken into account, this is an indication that rework or further refinement of the design is required.

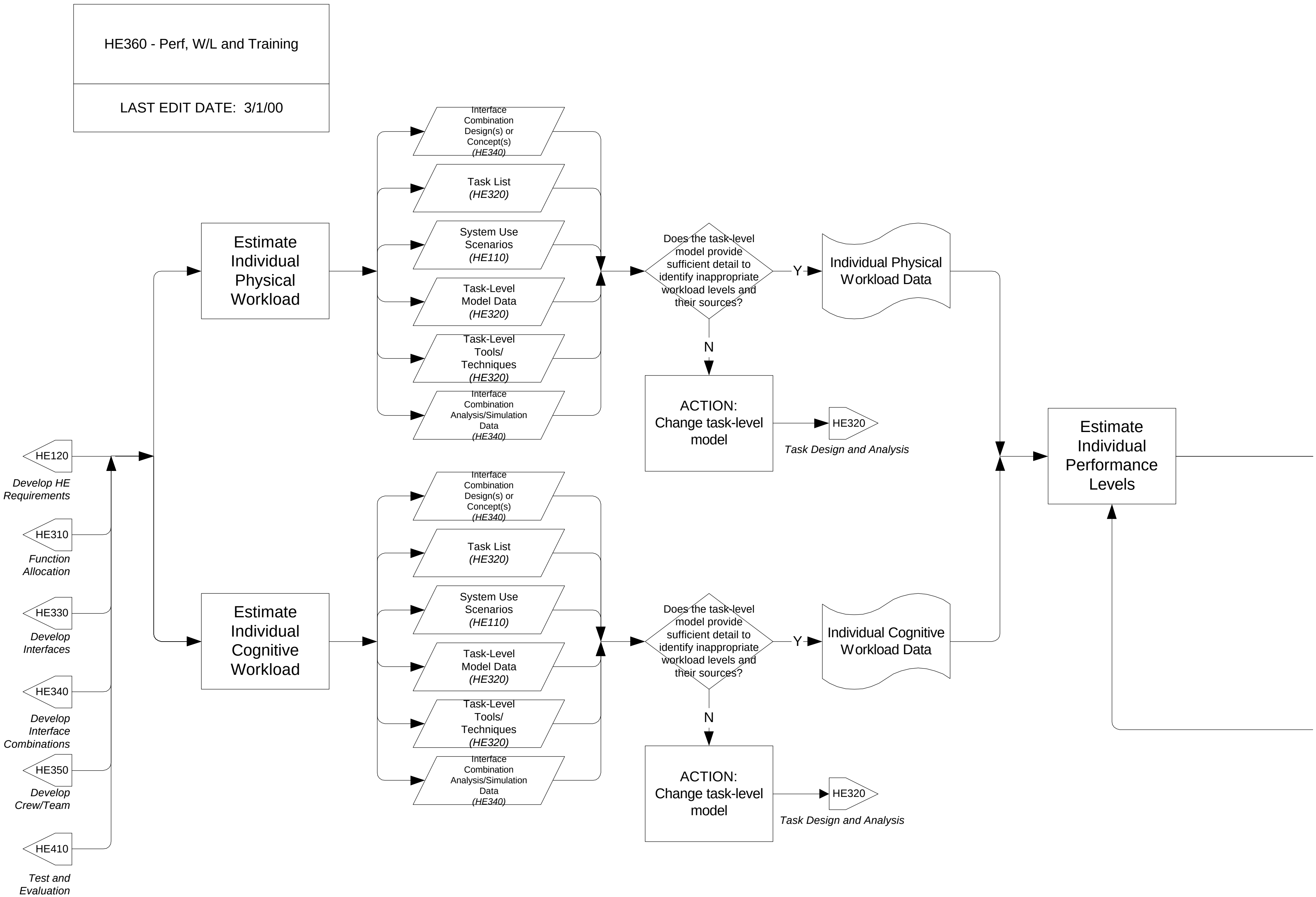
Sources:

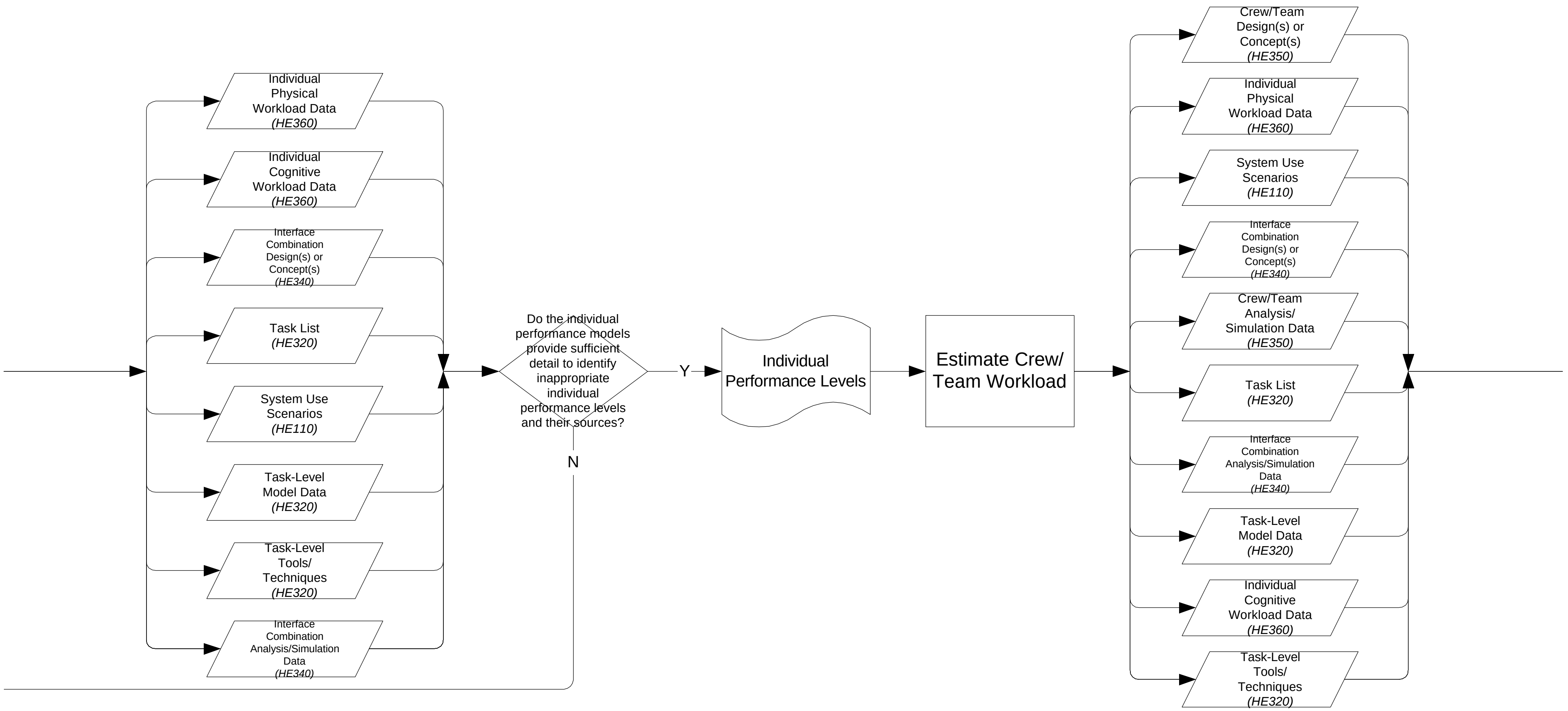
5. section 6.6.2.1

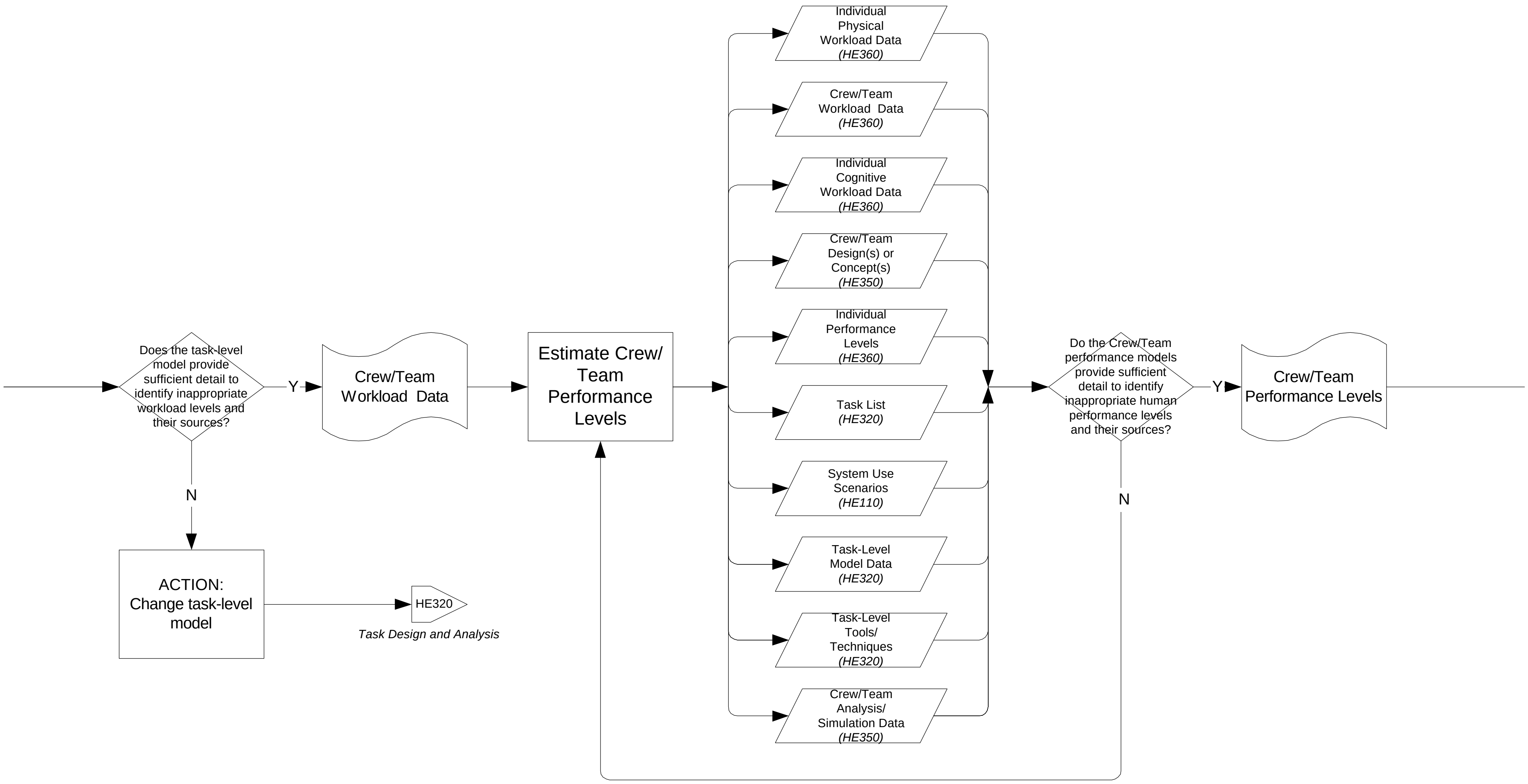
Significant Products:

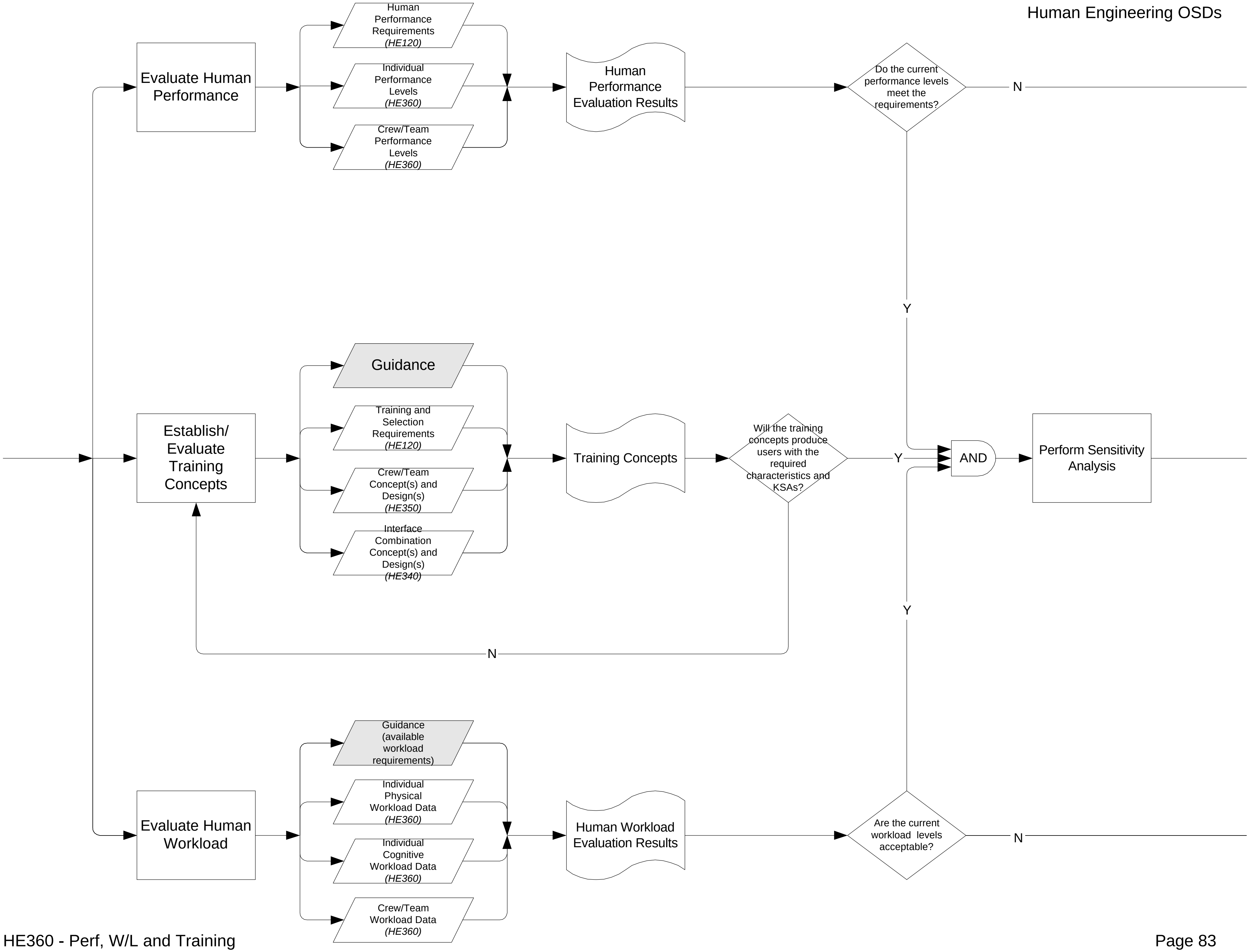
- Crew/Team Concept(s) or Design(s)
- Crew/Team-Specific Tasks
- Crew/Team Analysis/Simulation Data

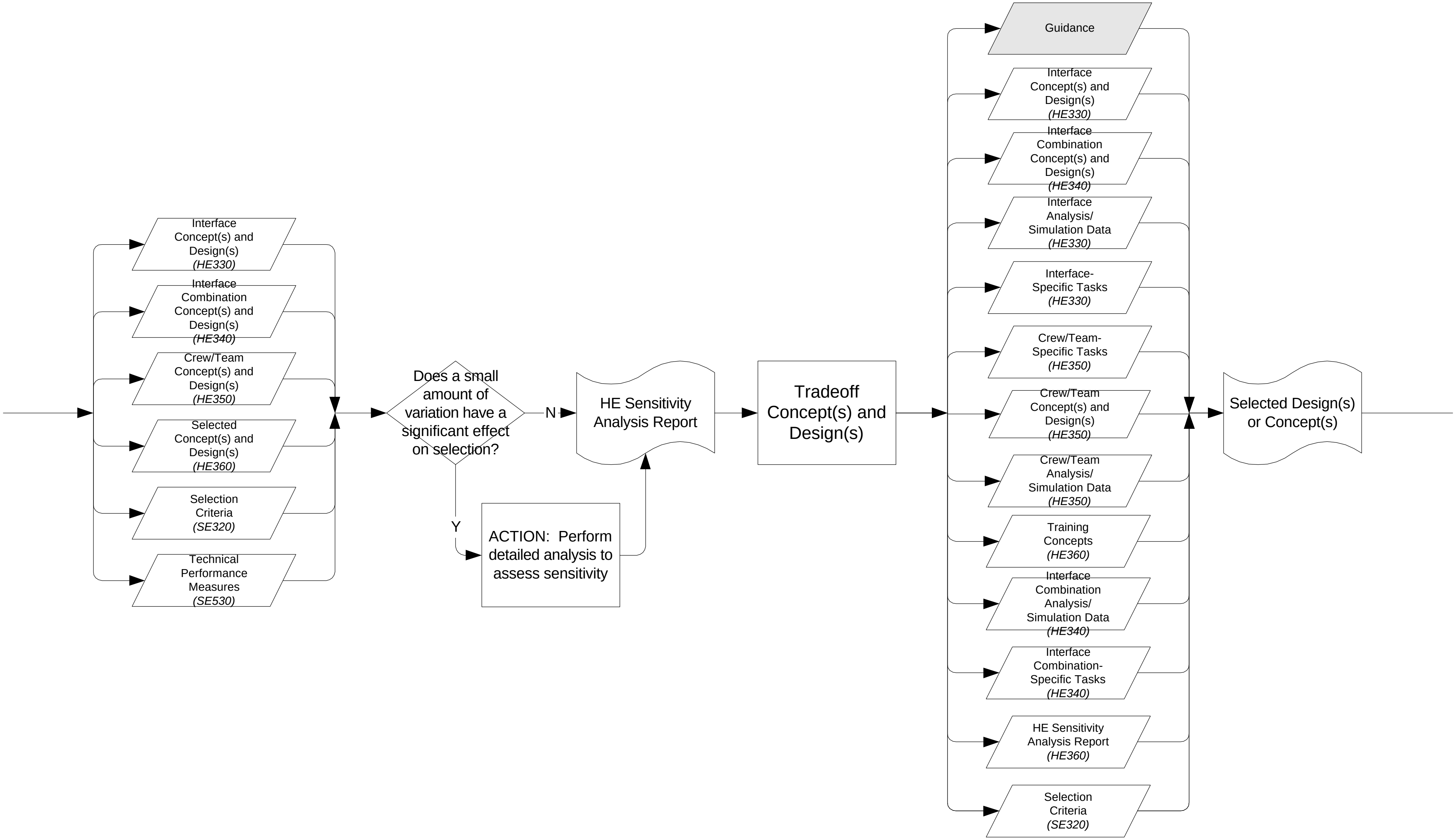
HE 360 – Estimate Performance, Workload, and Training Levels


HE360 - Perf, W/L and Training
LAST EDIT DATE: 3/1/00
HE120
Develop HE Requirements
HE310
Function Allocation
HE330
Develop Interfaces
HE340
Develop Interface Combinations
HE350
Develop Crew/Team
HE410
Test and Evaluation
Estimate Individual Physical Workload
Estimate Individual Cognitive Workload
Interface Combination Design(s) or Concept(s) (HE340)
Task List (HE320)
System Use Scenarios (HE110)
Task-Level Model Data (HE320)
Task-Level Tools/ Techniques (HE320)
Interface Combination Analysis/Simulation Data (HE340)
Does the task-level model provide sufficient detail to identify inappropriate workload levels and their sources?
Y
N
Individual Physical Workload Data
Individual Cognitive Workload Data
ACTION: Change task-level model
HE320
Task Design and Analysis
Estimate Individual Performance Levels

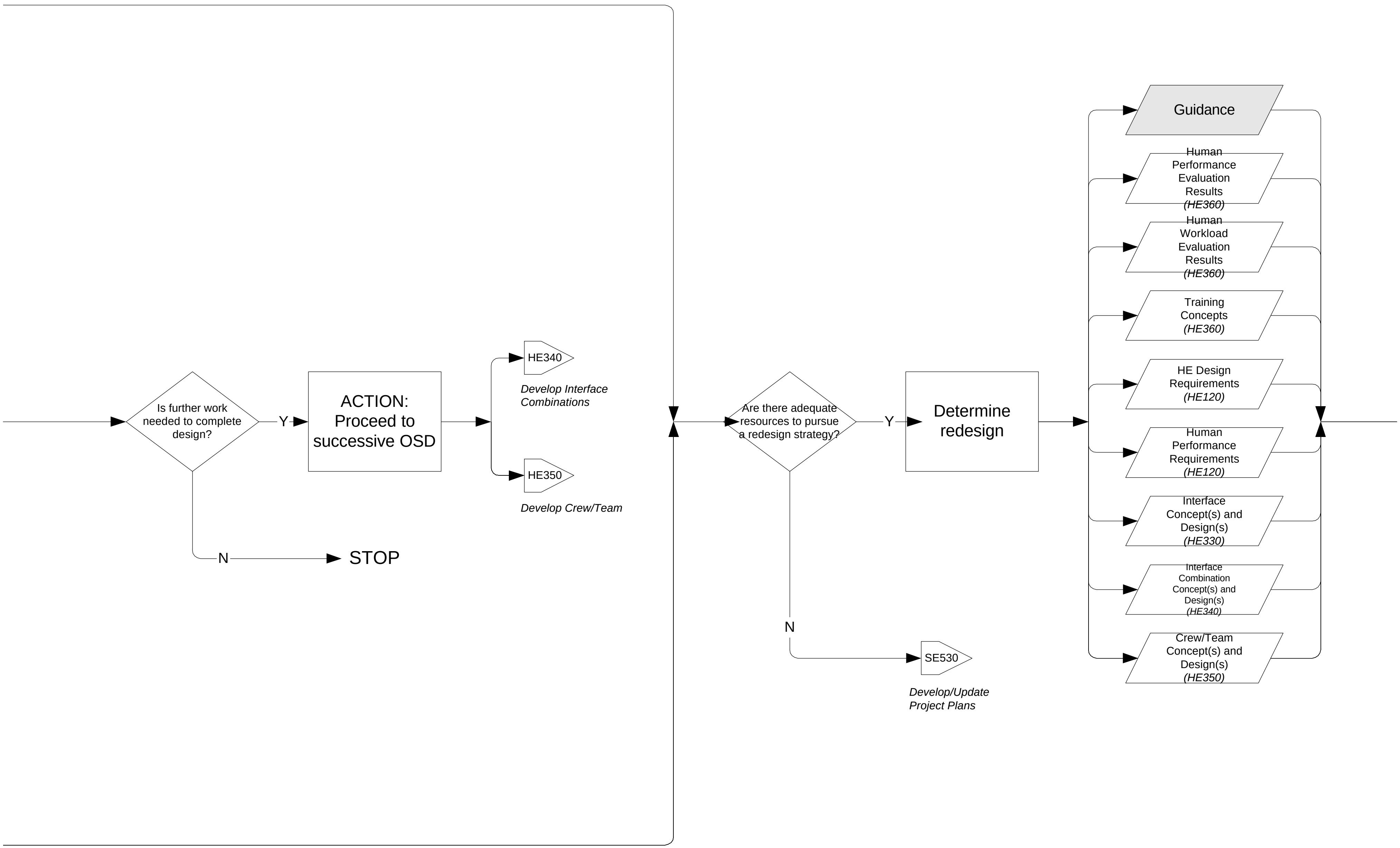

Individual Physical Workload Data (HE360)
Individual Cognitive Workload Data (HE360)
Interface Combination Design(s) or Concept(s) (HE340)
Task List (HE320)
System Use Scenarios (HE110)
Task-Level Model Data (HE320)
Task-Level Tools/ Techniques (HE320)
Interface Combination Analysis/Simulation Data (HE340)
Do the individual performance models provide sufficient detail to identify inappropriate individual performance levels and their sources?
Y
N
Individual Performance Levels
Estimate Crew/ Team Workload
Crew/Team Design(s) or Concept(s) (HE350)
Individual Physical Workload Data (HE360)
System Use Scenarios (HE110)
Interface Combination Design(s) or Concept(s) (HE340)
Crew/Team Analysis/ Simulation Data (HE350)
Task List (HE320)
Interface Combination Analysis/Simulation Data (HE340)
Task-Level Model Data (HE320)
Individual Cognitive Workload Data (HE360)
Task-Level Tools/ Techniques (HE320)

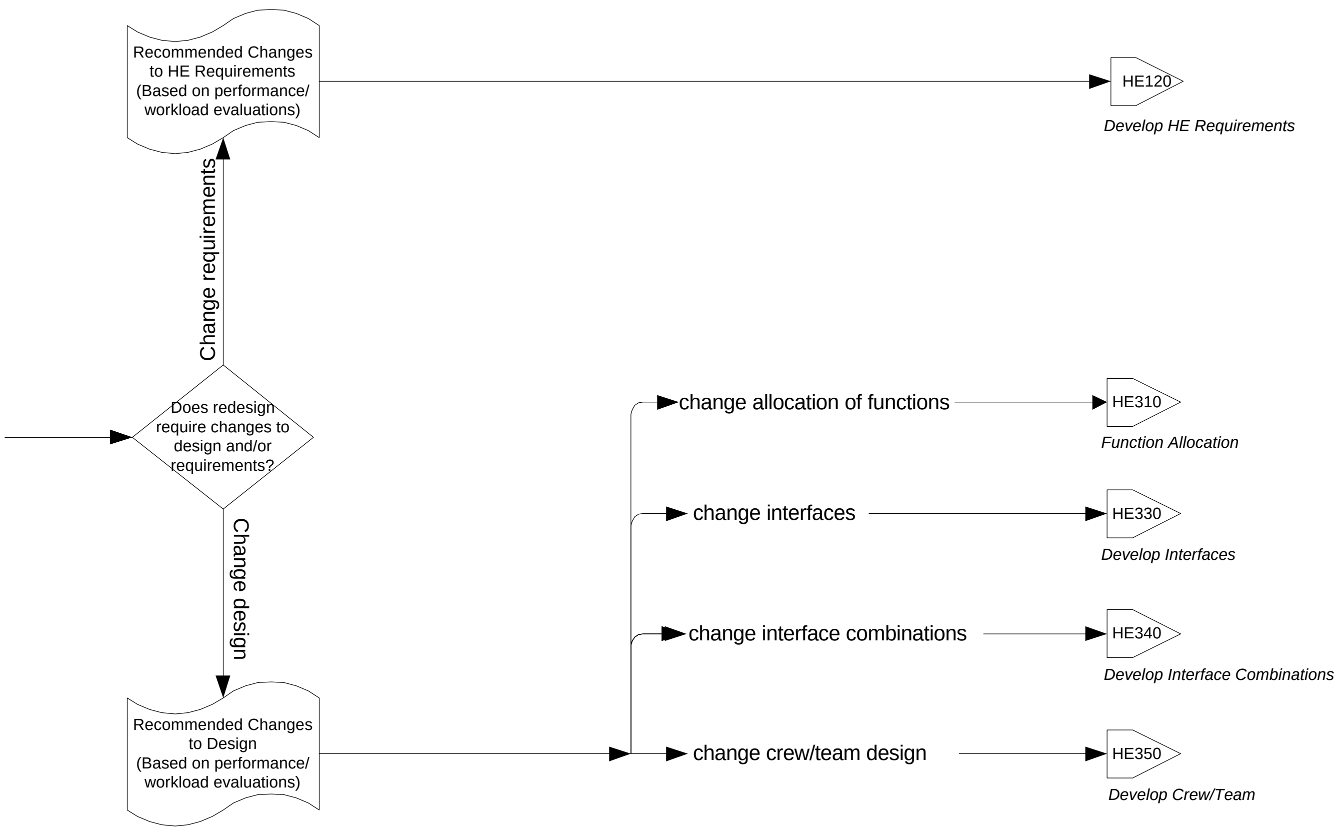

Does the task-level model provide sufficient detail to identify inappropriate workload levels and their sources?
Y
N
Crew/Team Workload Data
ACTION: Change task-level model
HE320
Task Design and Analysis
Estimate Crew/ Team Performance Levels
Individual Physical Workload Data (HE360)
Crew/Team Workload Data (HE360)
Individual Cognitive Workload Data (HE360)
Crew/Team Design(s) or Concept(s) (HE350)
Individual Performance Levels (HE360)
Task List (HE320)
System Use Scenarios (HE110)
Task-Level Model Data (HE320)
Task-Level Tools/ Techniques (HE320)
Crew/Team Analysis/ Simulation Data (HE350)
Do the Crew/Team performance models provide sufficient detail to identify inappropriate human performance levels and their sources?
Y
N
Crew/Team Performance Levels


Evaluate Human Performance
Human Performance Requirements (HE120)
Individual Performance Levels (HE360)
Crew/Team Performance Levels (HE360)
Human Performance Evaluation Results
Do the current performance levels meet the requirements?
N
Y
Establish/ Evaluate Training Concepts
Guidance
Training and Selection Requirements (HE120)
Crew/Team Concept(s) and Design(s) (HE350)
Interface Combination Concept(s) and Design(s) (HE340)
Training Concepts
Will the training concepts produce users with the required characteristics and KSAs?
Y
N
AND
Perform Sensitivity Analysis
Y
Evaluate Human Workload
Guidance (available workload requirements)
Individual Physical Workload Data (HE360)
Individual Cognitive Workload Data (HE360)
Crew/Team Workload Data (HE360)
Human Workload Evaluation Results
Are the current workload levels acceptable?
N



Interface Concept(s) and Design(s) (HE330)
Interface Combination Concept(s) and Design(s) (HE340)
Crew/Team Concept(s) and Design(s) (HE350)
Selected Concept(s) and Design(s) (HE360)
Selection Criteria (SE320)
Technical Performance Measures (SE530)
Does a small amount of variation have a significant effect on selection?
N
Y
ACTION: Perform detailed analysis to assess sensitivity
HE Sensitivity Analysis Report
Tradeoff Concept(s) and Design(s)
Guidance
Interface Concept(s) and Design(s) (HE330)
Interface Combination Concept(s) and Design(s) (HE340)
Interface Analysis/ Simulation Data (HE330)
Interface-Specific Tasks (HE330)
Crew/Team-Specific Tasks (HE350)
Crew/Team Concept(s) and Design(s) (HE350)
Crew/Team Analysis/ Simulation Data (HE350)
Training Concepts (HE360)
Interface Combination Analysis/ Simulation Data (HE340)
Interface Combination-Specific Tasks (HE340)
HE Sensitivity Analysis Report (HE360)
Selection Criteria (SE320)
Selected Design(s) or Concept(s)


Is further work needed to complete design?
Y
N
STOP
ACTION: Proceed to successive OSD
HE340
Develop Interface Combinations
HE350
Develop Crew/Team
Are there adequate resources to pursue a redesign strategy?
Y
N
SE530
Develop/Update Project Plans
Determine redesign
Guidance
Human Performance Evaluation Results (HE360)
Human Workload Evaluation Results (HE360)
Training Concepts (HE360)
HE Design Requirements (HE120)
Human Performance Requirements (HE120)
Interface Concept(s) and Design(s) (HE330)
Interface Combination Concept(s) and Design(s) (HE340)
Crew/Team Concept(s) and Design(s) (HE350)


Recommended Changes
to HE Requirements
(Based on performance/
workload evaluations)
HE120
Develop HE Requirements
Change requirements
Does redesign
require changes to
design and/or
requirements?
Change design
Recommended Changes
to Design
(Based on performance/
workload evaluations)
change allocation of functions
HE310
Function Allocation
change interfaces
HE330
Develop Interfaces
change interface combinations
HE340
Develop Interface Combinations
change crew/team design
HE350
Develop Crew/Team

HE 360 – Estimate Performance, Workload, and Training Levels

Narrative:

Once potential concepts and designs have been established, it is useful to estimate performance levels, workload, and training requirements for the designs in order to drive the iteration towards improvement. If low performance or inappropriate workload levels are noted or if lengthy and/or expensive training is required with the current potential designs, it is suggested that the designs be carefully reviewed and further design work take place. This is an important step in achieving both the goal of maximizing the effectiveness of the overall system design and in optimizing the demands on individual operators and the team as a whole.

The steps required at this phase in the process include an estimation of the physical and cognitive workload levels of individuals, as well as an estimation of the team workload levels within the system. Individual and team performance levels are also estimated and all of these predictions are used to create evaluations of the overall workload and performance levels. Training is also a crucial factor, and training concepts should be carefully developed and evaluated. Workload, performance, and training are each important considerations in the sensitivity analysis of the alternative concepts and designs and tradeoff that follows. Finally, redesign options are considered and changes to the requirements or designs made as necessary.

<u>Estimate Individual Physical Workload</u>

Given the current stage of the interface design and the tasks allocated to each human, it is necessary to estimate the physical workload (perceptual, psychomotor, physiological, etc.) demands of the tasks. Workload should be considered for each position and under varying conditions and situations (as defined in the System Use Scenarios). Workload stressors and their effects on human performance also need to be identified, as well as operator coping strategies, and the effects of task neglect/delay.

Types of general workload assessment that may be useful include primary task measures, secondary task measures, subjective rating measures, and physiological measures. Primary task measures can consider the operator's performance on the task of interest, or the expected task performance based on a timeline analyses of workload, task analyses, or models. Secondary task measures have the operator take on a task in addition to the task of interest, and the operator may be asked to concentrate on either task. This technique is hypothesized to show the performance on the primary task when the operator is under stress and to demonstrate the plausibility of additional processing that can be undertaken by an operator engaged in the task of interest. Subjective workload rating scales such as the modified Cooper-Harper scale and the NASA-Task Load Index (TLX) are also commonly utilized. These scales, or interviews that attempt to gather similar data, ask the operators to rate their subjective assessment of the workload of the task. The final category of measurement is the assessment of physiological measures, or how the body responds to the task situation. Examples of physiological measures include heart rate and nervous system activity.

There are a number of workload estimation methods available and the decision of which to employ is a complex one. Examples of the factors that should be taken into account when selecting a method are the task domain, task complexity, and the expense, difficulty, and intrusiveness of the method. Some techniques are obviously more applicable to physical workload assessment than others. If both physical and cognitive workloads are to be assessed, it may be cost-effective to select a method that will provide feedback on both facets of operator workload simultaneously. However, if the task is such that high or unusual physical demands are expected, additional analysis is advised. Physical stress surveys may be utilized, as well as lifting, strength, and posture analysis.

Sources:

4. V2I2 sections 5.1-5.6
6. section 3.2.1.3.3
7. section 4.3.4
8. pages 262-290
17. pages 749-782
18. sections 7.2-7.3

<u>Estimate Individual Cognitive Workload</u>

Given the designed tasks allocated to each human, it is necessary to estimate the cognitive workload (short term/working memory, decision making, sensory processing, etc.) demands of the tasks. Workload should be considered for each position and under varying conditions and situations (as defined in the System Use Scenarios. Workload stressors and their effects on human performance also need to be identified, as well as operator coping strategies, and the effects of task neglect or delay.

Types of general workload assessment that may be useful include primary task measures, secondary task measures, subjective rating measures, and physiological measures. Primary task measures consider the operator's performance on the task of interest, or the expected task performance based on a timeline analyses of workload, task analyses, or models. Secondary task measures have the operator take on a task in addition to the task of interest, and the operator may be asked to concentrate on either task. This technique is hypothesized to show the performance on the primary task when the operator is under stress and to demonstrate the plausibility of additional processing that can be undertaken by an operator engaged in the task of interest. Subjective workload rating scales such as the modified Cooper-Harper scale, the Subjective Workload Assessment Technique (SWAT) (primarily cognitive), and the NASA-Task Load Index (TLX) are also commonly utilized. These scales, or interviews that attempt to gather similar data, ask the operators to rate their subjective assessment of the workload of the task. The final category of measurement is the assessment of physiological measures, or how the body responds to the task situation. Examples of physiological measures include heart rate and nervous system activity.

There are a number of cognitive workload estimation methods available and the decision of which to employ is a complex one. Examples of the factors that should be taken into account when selecting a method are the task domain, task complexity, and the expense, difficulty, and intrusiveness of the method. As with physical workload, some techniques are more applicable to cognitive workload assessment than others. If both physical and cognitive workloads are to be assessed, it may be cost-effective to select a method that will provide feedback on both facets of operator workload simultaneously. However, if the task is such that high or unusual cognitive demands are expected, additional cognitive analysis is advised.

Sources:

4. V2I2 sections 5.1-5.6
6. section 3.2.1.3.3
7. section 4.3.4
8. pages 262-290
15. sections 13.1-13.3
17. pages 749-766

Estimate Individual Performance Levels

Once workload levels are predicted, performance measures can be adjusted to determine the impact of workload. Human performance modeling is a crucial link in the design process in order to ensure that humans have been properly accounted for and that they can be expected to complete the necessary tasks as anticipated. More specifically, modeling the performance of individual operators facilitates an understanding of how humans interact with the system and what is required of them, how best to allocate functions to the system components, and how other variables such as workload affect performance. Executable models or simulations are typically used, but subjective feedback from test users or subject matter experts may also be employed. Thus, performance estimates can also be based on user testing completed as a part of the *Test and Evaluation* process.

Models of human performance may be at varying levels of detail and the appropriate level of complexity will depend on the domain and the current stage in system development. The goal of the performance estimation will also influence the task level that is modeled, from the basic perception or keystroke level, up to highly complex cognitive tasks. Models can be utilized to predict performance on a variety of types of tasks such as manual control, signal detection, decision making, cognitive processing, and supervisory control. The types of models used may include simple formulas or complicated computer simulations.

Sources:

1. section 2.3.4
7. section 2.9.4
8. pages 331-338, 433-468
26. page 745
38. section 37.1-37.6
39. sections 38.1-38.8
40. section 39.8
41. sections 40.1-40.6
42. sections 41.1-41.7
43. page 6

Estimate Crew/Team Workload

Estimating the workload of the entire team is an opportunity to examine the “big picture” and compare the workload across team members. For example, if one operator is overloaded while others are struggling with vigilance, or another example of uneven workload distribution is apparent, then this will be an important consideration in the workload evaluation and the distribution of tasks among the team members should probably be reallocated. The assessment of each individual is based on the individual cognitive and physical metrics utilized earlier in the phase.

To supplement the strategy of adding individual workloads, ongoing research is being conducted examining crew/team workload metrics. Researchers are also testing the use of converting the individual workload measures to the team level. For example, some researchers have noted their use of SWAT to review team subjective workload. The overall goal of this step is to estimate the workload demands on each individual and the group as a whole given the defined tasks allocated to the team.

Sources:

6. section 3.2.1.3.3
8. pages 262-290
23. page 184
27. pages 303-307

Estimate Crew/Team Performance Levels

Once the individual performance estimations are completed, it is useful to consider the performance of the crew/team as a whole. Although the performance of some individuals may be acceptable, the performance of others might be lacking. Examining the team collectively provides an opportunity for estimating these variances, which can be corrected during the performance evaluation. It is also crucial to test the team performance because additional tasks or demands unique to the team environment may alter the performance of individual team members.

Although the number of team performance models is not as extensive as with individual models, a wide variety of choices are still available. Model selection should be based on the domain, the current status of the design, and the projected use of the performance data. Mathematical models are popular and are available for topics such as information processing, decision making, and resource allocation. Performance data can also be gathered via team-in-the-loop testing in the field or in simulations of varying levels of fidelity.

Sources:

7. section 2.9.4
22. pages 153-172
23. pages 177-215
28. pages 308-312

Evaluate Human Performance

Both the individual and crew level performance analysis that was previously undertaken should be compared with performance requirements for the project. Acceptable performance levels for different mission phases should be identified taking into account criticality of the system performance, fault tolerance, and time available for error correction. The previous steps focused on the gathering of performance data. Here the data is reviewed, combined or compared with other measures, and analyzed to determine a verdict as to the overall performance of the humans within the system.

Expert judgment will also be necessary to decide whether the performance level is optimal, acceptable, or a driver for further redesign.

It is important to note that the goal of this step is not to maximize human performance, but performance of the system overall. Designing for optimal performance by humans may limit other aspects of the system. Thus, a holistic approach should be taken in close coordination with the entire design team.

Sources:

1. section 2.3.4
7. section 2.9.4
8. pages 433-468
22. pages 153-172
23. pages 177-215
26. page 745

<u>Establish/Evaluate Training Concepts</u>

The resources required to field and maintain a system are typically key concerns. The users are frequently the most often changed and varied parts of the system. The training required to prepare them for use of the system and to maintain their qualifications as users are important parts of the system design.

The difference between the knowledge, skills, and abilities required to be a system user and the knowledge, skills, and abilities possessed by prospective users will have been determined in the training and selection requirements. Additionally, human interfaces can be designed to provide for either ease-of-use or ease-of-learning. It is rare to be able to maximize both of these qualities, and their relative importance will influence the design of tasks, interfaces, and teams, all of which will in turn influence required training. Requirements such as those for on-the-job training or embedded training should have been stated early to reduce the likelihood of design changes to meet the requirements at a later date.

Training concepts may include the use of an instructor, computer-assisted training, audiovisual techniques, simulations, etc. The potential training concepts need to be evaluated to verify that they meet the training and selection requirements. The results of the training evaluation will also be an important variable in the design tradeoffs, along with other variables such as performance and cost.

Sources:

7. sections 3.11.2, 3.12.12
8. pages 391-414
9. pages 260-268
16. pages 265-268
29. pages 313-317

<u>Evaluate Human Workload</u>

Both the individual and crew level workload analysis that was previously undertaken should be compared with workload limits for the domain, as well as the performance criteria. Acceptable workload limits for different mission phases should be identified taking into account time and environmental effects. The previous steps focused on the gathering of workload data. Here the data is reviewed, combined or compared with other measures or guidelines, and analyzed to determine a verdict as to the overall human workload level within the system. Expert judgment will also be necessary to decide whether the workload level is optimal, acceptable, or a driver for further redesign.

When workload is evaluated, the emphasis is often on ensuring that operators are not overloaded. However, it is possible that operators can be under-loaded, resulting in problems such as vigilance, boredom, and/or loss of muscle tone. Therefore, the goal is not to minimize workload, but to optimize it.

Sources:

4. V2I2 sections 5.1-5.6
6. section 3.2.1.3.3
7. section 3.12.4.4
8. pages 262-290

Perform Sensitivity Analysis

Before tradeoffs have been made, it is desirable to examine the robustness of the chosen design. A sensitivity analysis should be conducted where possible variations in the criteria, methodology, scenarios, and/or assumptions are evaluated. If small changes in these values result in large impacts on a design's utility, that design may be deemed too sensitive to variation and a more robust design option considered. A sensitivity analysis is also a useful technique when faced with multiple designs that are closely ranked given the set criteria. If advantages to one design do not become clear, new selection methods or expanded criteria can help narrow the options.

Sources:

9. pages 285-286
19. page 423
24. pages 103-104
25. section 4.4.4.B.5

Tradeoff Concept(s) and Design(s)

Once estimates of subsystem or component performance are available, tradeoffs can be conducted between different design alternatives to determine the best option. If multiple alternatives meet the system's functional and performance requirements, then those alternatives should be compared to select the optimal design. Typically, different options will have different strengths and weaknesses, so choosing an option that is strong in one area may decrease performance in other areas. For this reason it is important to have already determined the relative importance of the different design criteria to be used. If the design criteria are identified early in the process, it reduces the likelihood of bias being introduced during the tradeoffs. Even if a formal trade study approach is not employed, the definition of the design criteria will help to justify the selections and make it easier to deal with subsequent changes to system design.

Sources:

5. section 6.7.9
7. sections 1.4.8, 1.7.2-1.7.4
9. pages 281-282
20. section 9.2

Determine Redesign

If it is determined that either performance or workload levels are not acceptable in the current design, then redesign is in order. For example, if it is found that the operators simply cannot meet the specified human performance requirements or that unsatisfactory workload levels exist, this will necessitate either a change to the requirements or an addition to the design to provide further support.

Based on the evaluation results, training, and additional systems engineering input, it must be determined where the problem lies and whether the requirements and/or design merit change. If requirements need to be updated, then the revised requirements will be compared with the design, or the new design as altered to concur with the new requirements. If the design is to be altered, depending on the type of change mandated (e.g., changing the interface, changing the crew/team, etc.) the design process should go back to the phase that is applicable and review the previous decisions. Since this is an iterative process, the design loop can cycle through many times before a satisfactory selected design is reached.

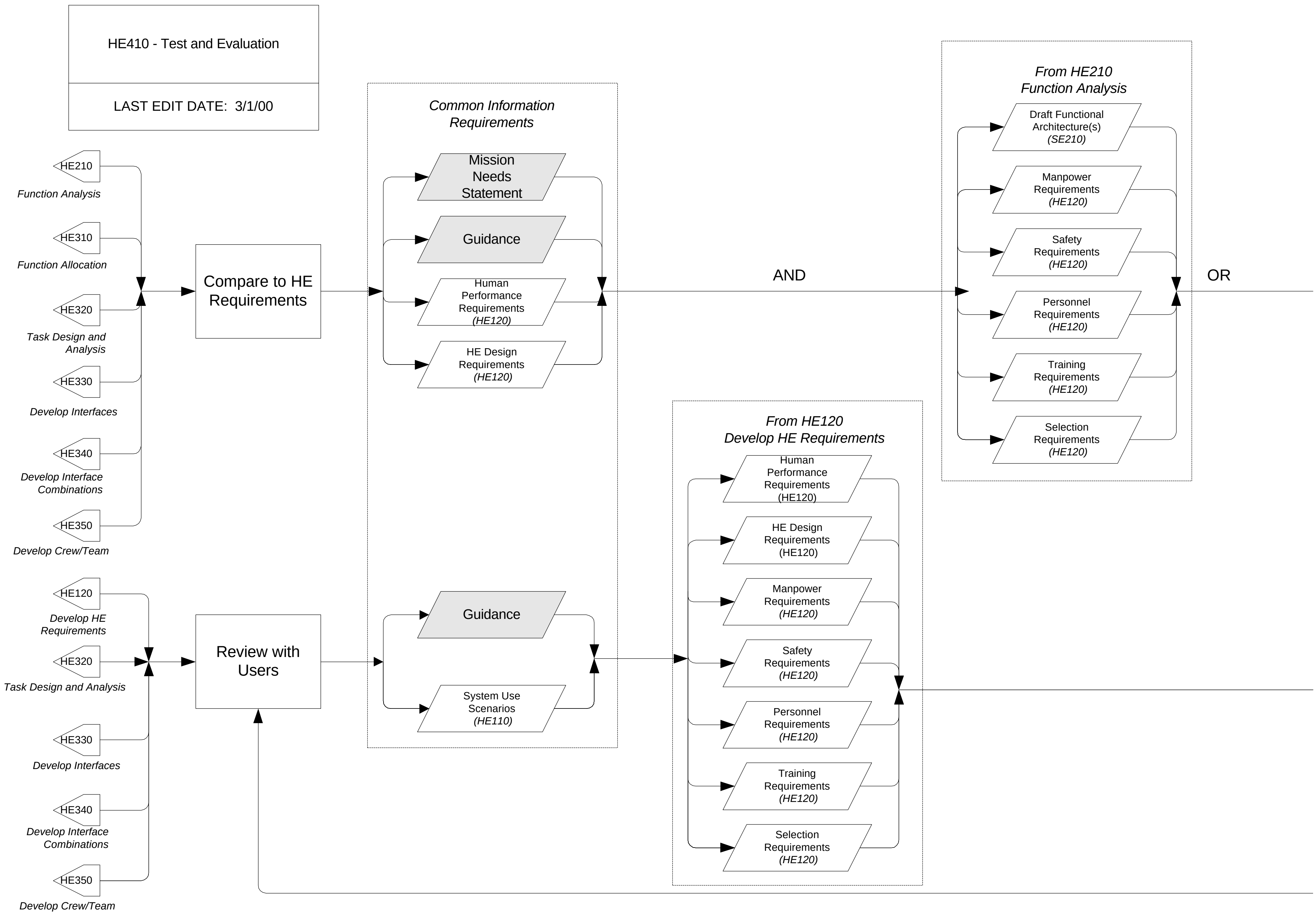
Sources:

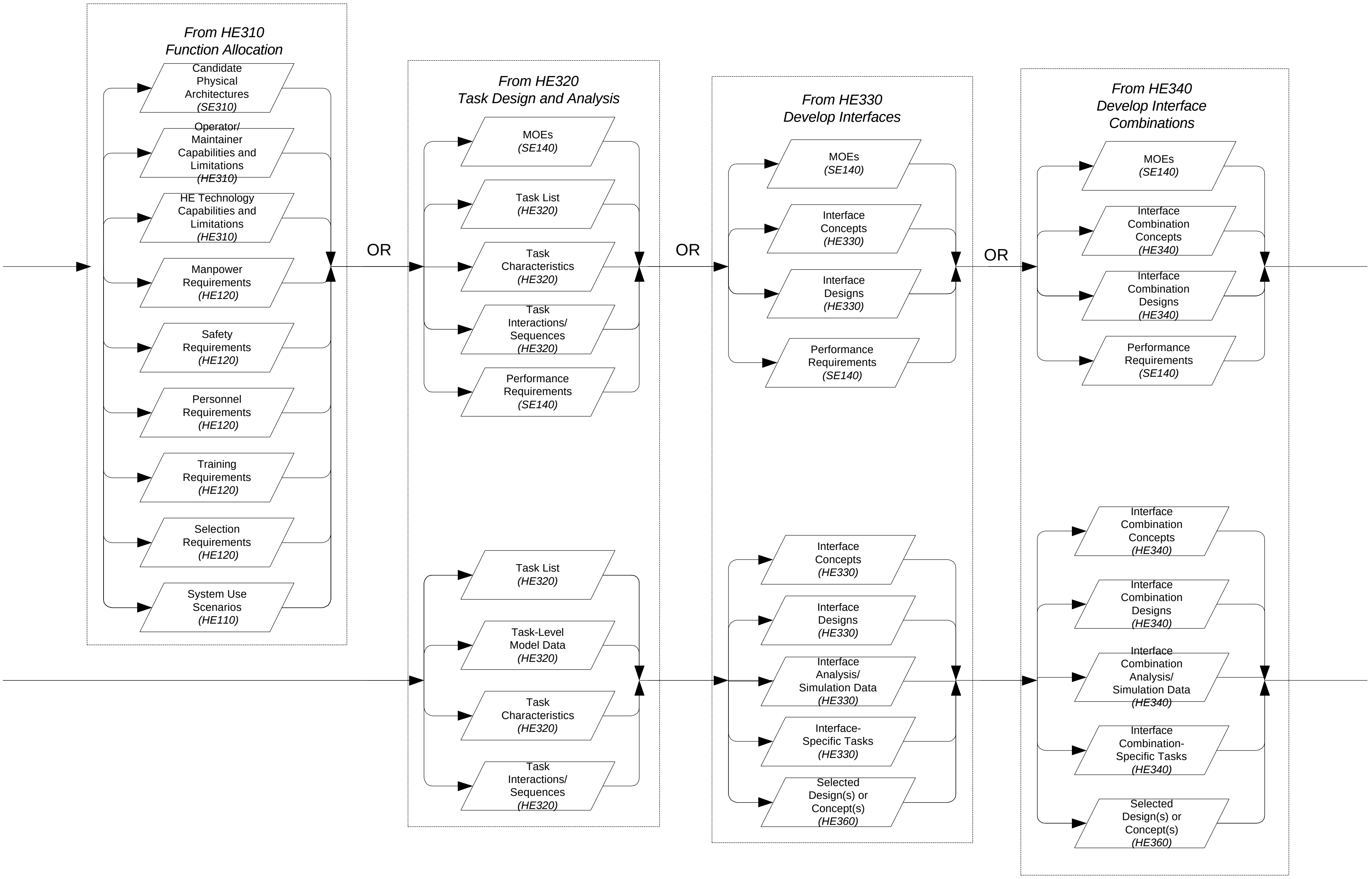
5. section 5.4.2

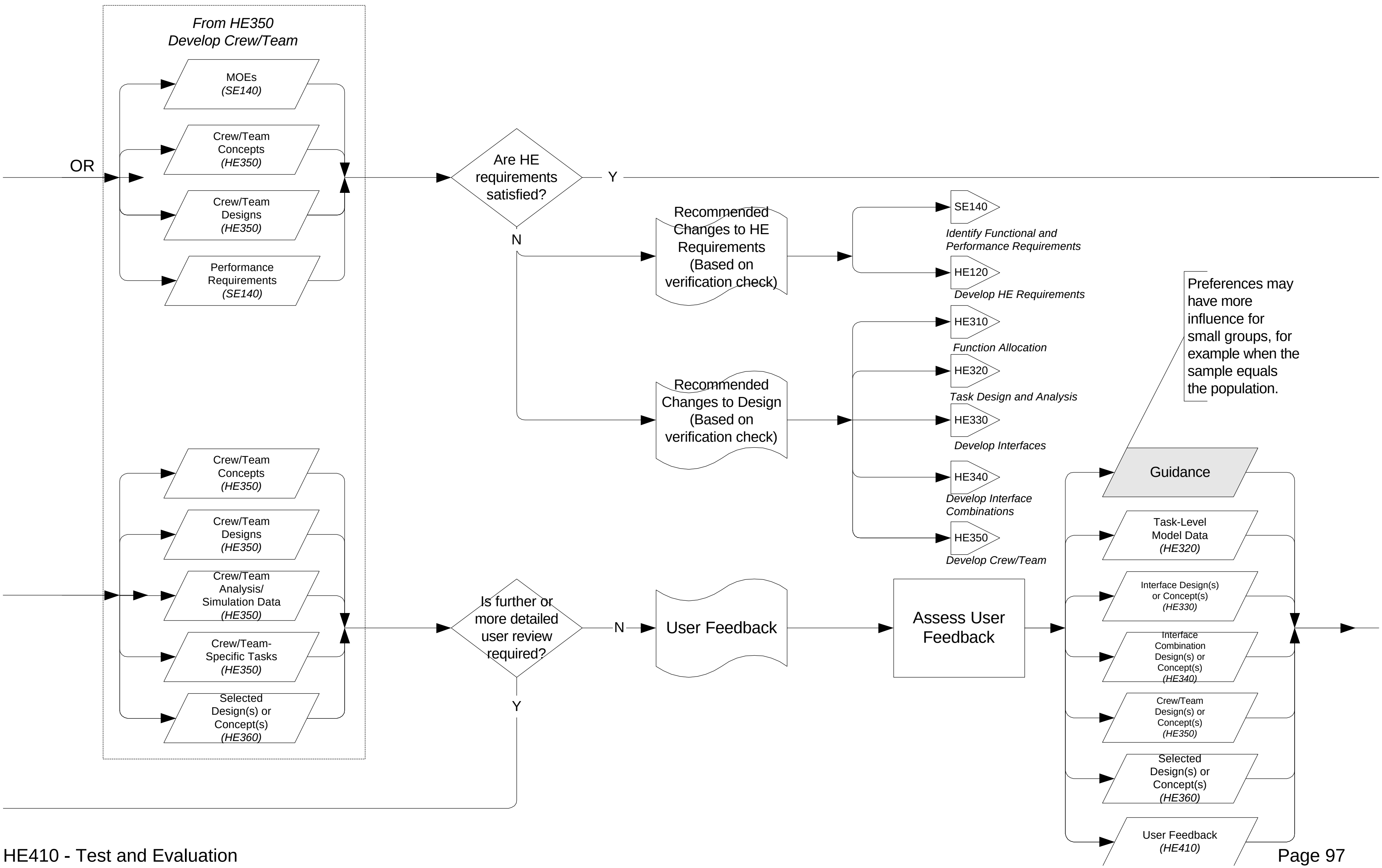
Significant Products:

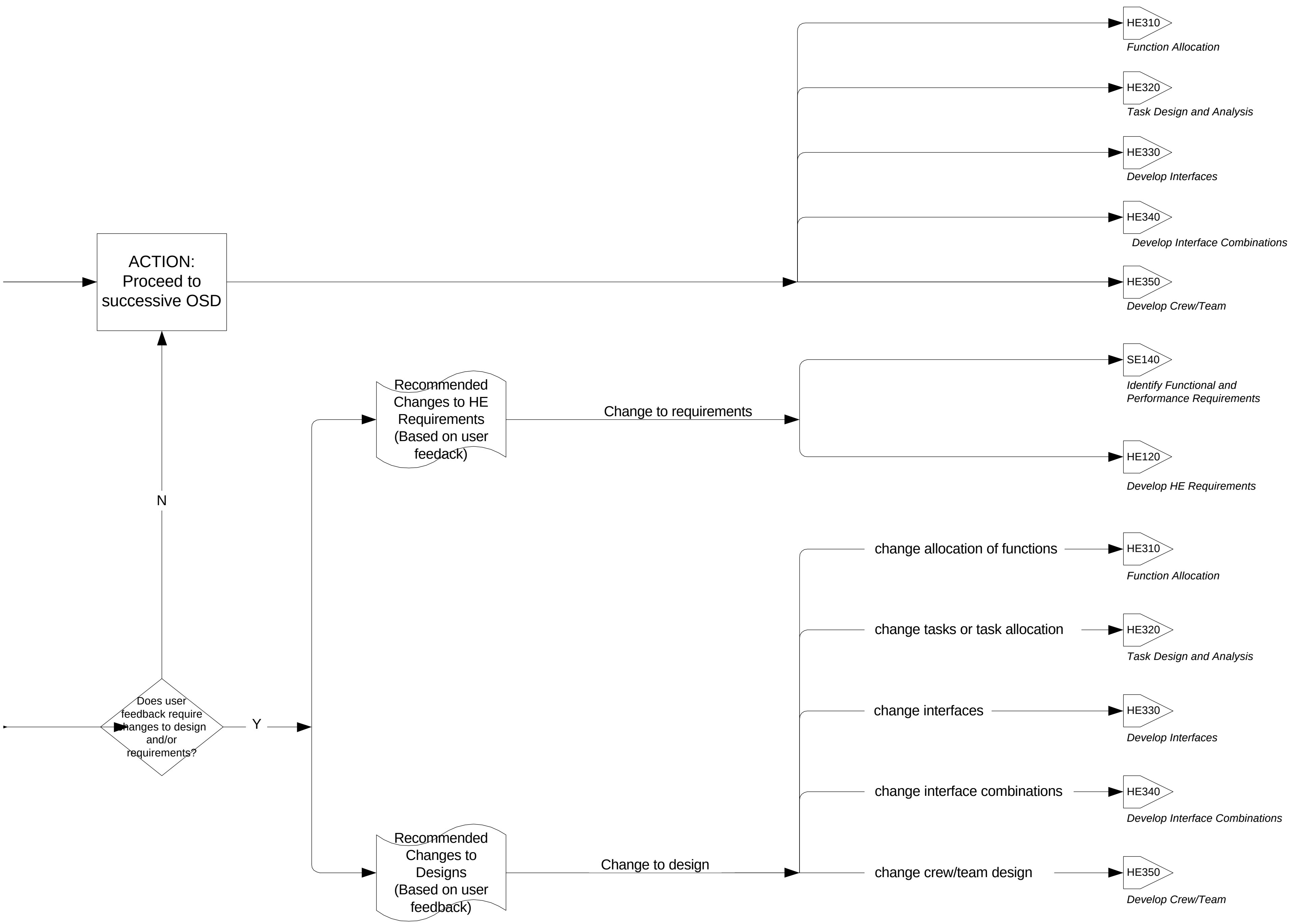
- Individual Physical Workload Data
- Individual Cognitive Workload Data
- Individual Performance Levels
- Crew/Team Workload Data
- Crew/Team Performance Levels
- Human Performance Evaluation Results
- Training Concepts
- Human Workload Evaluation Results
- Selected Design(s) or Concept(s)
- Sensitivity Analysis Report
- Recommended Changes to HE Requirements
- Recommended Changes to Designs

HE 410 – Test and Evaluation


HE410 - Test and Evaluation
LAST EDIT DATE: 3/1/00
HE210
Function Analysis
HE310
Function Allocation
HE320
Task Design and Analysis
HE330
Develop Interfaces
HE340
Develop Interface Combinations
HE350
Develop Crew/Team
Compare to HE Requirements
Common Information Requirements
Mission Needs Statement
Guidance
Human Performance Requirements (HE120)
HE Design Requirements (HE120)
AND
From HE210 Function Analysis
Draft Functional Architecture(s) (SE210)
Manpower Requirements (HE120)
Safety Requirements (HE120)
Personnel Requirements (HE120)
Training Requirements (HE120)
Selection Requirements (HE120)
OR
HE120
Develop HE Requirements
HE320
Task Design and Analysis
HE330
Develop Interfaces
HE340
Develop Interface Combinations
HE350
Develop Crew/Team
Review with Users
Guidance
System Use Scenarios (HE110)
From HE120 Develop HE Requirements
Human Performance Requirements (HE120)
HE Design Requirements (HE120)
Manpower Requirements (HE120)
Safety Requirements (HE120)
Personnel Requirements (HE120)
Training Requirements (HE120)
Selection Requirements (HE120)


From HE310
Function Allocation
Candidate Physical Architectures (SE310)
Operator/ Maintainer Capabilities and Limitations (HE310)
HE Technology Capabilities and Limitations (HE310)
Manpower Requirements (HE120)
Safety Requirements (HE120)
Personnel Requirements (HE120)
Training Requirements (HE120)
Selection Requirements (HE120)
System Use Scenarios (HE110)
OR
From HE320
Task Design and Analysis
MOEs (SE140)
Task List (HE320)
Task Characteristics (HE320)
Task Interactions/ Sequences (HE320)
Performance Requirements (SE140)
Task List (HE320)
Task-Level Model Data (HE320)
Task Characteristics (HE320)
Task Interactions/ Sequences (HE320)
OR
From HE330
Develop Interfaces
MOEs (SE140)
Interface Concepts (HE330)
Interface Designs (HE330)
Performance Requirements (SE140)
Interface Concepts (HE330)
Interface Designs (HE330)
Interface Analysis/ Simulation Data (HE330)
Interface-Specific Tasks (HE330)
Selected Design(s) or Concept(s) (HE360)
OR
From HE340
Develop Interface Combinations
MOEs (SE140)
Interface Combination Concepts (HE340)
Interface Combination Designs (HE340)
Performance Requirements (SE140)
Interface Combination Concepts (HE340)
Interface Combination Designs (HE340)
Interface Combination Analysis/ Simulation Data (HE340)
Interface Combination-Specific Tasks (HE340)
Selected Design(s) or Concept(s) (HE360)


From HE350
Develop Crew/Team
MOEs
(SE140)
Crew/Team
Concepts
(HE350)
Crew/Team
Designs
(HE350)
Performance
Requirements
(SE140)
OR
Are HE
requirements
satisfied?
Y
N
Recommended
Changes to HE
Requirements
(Based on
verification check)
SE140
Identify Functional and
Performance Requirements
HE120
Develop HE Requirements
Recommended
Changes to Design
(Based on
verification check)
HE310
Function Allocation
HE320
Task Design and Analysis
HE330
Develop Interfaces
HE340
Develop Interface
Combinations
HE350
Develop Crew/Team
Preferences may
have more
influence for
small groups, for
example when the
sample equals
the population.
Crew/Team
Concepts
(HE350)
Crew/Team
Designs
(HE350)
Crew/Team
Analysis/
Simulation Data
(HE350)
Crew/Team-
Specific Tasks
(HE350)
Selected
Design(s) or
Concept(s)
(HE360)
Is further or
more detailed
user review
required?
N
Y
User Feedback
Assess User
Feedback
Guidance
Task-Level
Model Data
(HE320)
Interface Design(s)
or Concept(s)
(HE330)
Interface
Combination
Design(s) or
Concept(s)
(HE340)
Crew/Team
Design(s) or
Concept(s)
(HE350)
Selected
Design(s) or
Concept(s)
(HE360)
User Feedback
(HE410)


ACTION: Proceed to successive OSD
HE310
Function Allocation
HE320
Task Design and Analysis
HE330
Develop Interfaces
HE340
Develop Interface Combinations
HE350
Develop Crew/Team
Recommended Changes to HE Requirements (Based on user feedack)
Change to requirements
SE140
Identify Functional and Performance Requirements
HE120
Develop HE Requirements
N
Does user feedback require changes to design and/or requirements?
Y
change allocation of functions
HE310
Function Allocation
change tasks or task allocation
HE320
Task Design and Analysis
change interfaces
HE330
Develop Interfaces
change interface combinations
HE340
Develop Interface Combinations
Recommended Changes to Designs (Based on user feedback)
Change to design
change crew/team design
HE350
Develop Crew/Team

HE 410 – Test and Evaluation

Narrative:

Test and evaluation is both an important and an unusual phase because it occurs at a number of points throughout the design process. As such, it is highly variable due to the fact that the inputs into the phase (i.e., the current design) vary as iterations take place and as the high-level initial inputs get further developed and increase in detail and complexity. However, testing and evaluation should not be thought of as a simply an obligation to be fulfilled, but as a crucial and informative phase that often helps keep the design in line with the needs and abilities of the end-users. It is imperative that testing be conducted early and often. If a design is determined to be inappropriate for users after a significant portion of the design has already taken place, then changes to remedy the problem later can be costly and time-consuming. A few minutes with a user early in the process can save months of corrective work later.

There are two aspects to the test and evaluation process. First, the design must be compared with the human engineering (HE) requirements to verify that these requirements were considered and that the design conforms to their specifications. Second, the design should be reviewed with users and their feedback assessed. The appropriate extent and type of user review selected will depend on the current stage of the design process. If problems are uncovered in either the requirements or user review, then the cause of those problems must be addressed and changes made to the HE requirements, the design, or both.

<u>Compare to HE Requirements</u>

As system designs are generated from requirements, those designs must then be verified to ensure that the requirements are satisfied. The specific human engineering requirements, such as design requirements and human performance requirements, must be used to evaluate the designs. A majority of the verification process will typically be spent on task, job, or equipment designs specific to human engineering. Other designs, however, will have to be reviewed for compatibility with human engineering requirements. Verification may be performed through a variety of different means, ranging from inspection to modeling and simulation to user-in-the-loop testing. If requirements are not satisfied, it should be determined whether changes to HE requirements are required or if the design itself should be changed, or perhaps both. The design process should cycle back to assimilate whatever changes are deemed appropriate.

Sources:

5. section 6.6.2
24. page 55

<u>Review with Users</u>

Verification that the design of a system conforms to requirements is important, but the system design must also be validated. The system needs to meet to the needs of the users or purchasers, and precise verification of written requirements does not always provide such assurance. Although reviewers such as representative users or subject matter experts (SMEs) may be able to provide some feedback from requirements and functional descriptions, especially effective feedback can be generated from the review of proposed physical designs. Reviewing these designs with intended users through means such as System Use Scenarios, storyboards, simulations, and mock-ups can provide early and rapid validation feedback and may find problems that have been left undetected by a requirements or function review. If "users" are not available, SMEs and/or heuristics might be employed instead.

As a complement to the user reviews of proposed designs, human-in-the loop testing can provide additional crucial feedback (criticality depends on the mission, the human role, and the current design stage). User testing may be done utilizing tools such as prototypes and static or dynamic models. The appropriate fidelity for the test will depend on the type of information needed and the type of design decisions it will influence. Full validation that the system meets the operational need may not occur until the system is operational and fielded.

Sources:

7. section 5.11
8. pages 433-468
30. pages 249-279
31. sections 15.1-15.7
32. pages 7-33
33. pages 124-149
35. sections 29-34

<u>Assess User Feedback</u>

Through eliciting user feedback, problems with the current design may be discovered and may drive changes either to the design, the requirements, or both. However, not all feedback gathered from users will be relevant or valid. Changes to the system design or requirements should be based on an objective analysis of information, not on the subjective preferences or opinions of a small group of reviewers (unless the population itself is small). Once feedback has been collected, it is necessary to evaluate the feedback to determine what changes should be considered. Depending on the type of problems uncovered in the assessment, the user difficulties should be addressed by changes to the design, requirements, or some combination of both.

Sources:

7. section 5.12
12. sections 10.5, 10.6
34. pages 299-343

Significant Products:

- User Feedback
- Recommended Changes to HE Requirements (Based on User Feedback or verification check)
- Recommended Changes to Designs (Based on User Feedback or verification check)

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